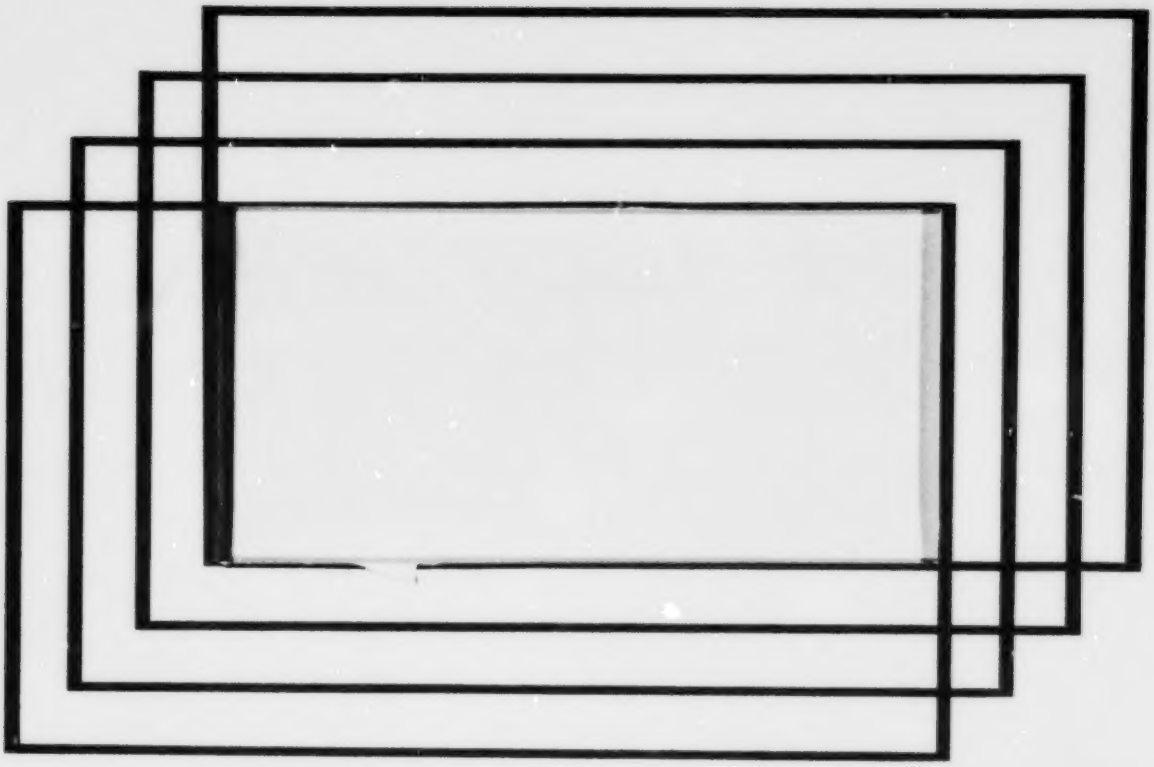

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Container Terminal Simulation Model
User's Manual

by

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17. Abstract

The Container Terminal Simulation is a computer simulation of the major operations in an inland container terminal: inbound train arrivals and unloading, outbound trains departures and loading, storage of containers arriving by train or by truck, customer pick-up of containers. The model consists of a batch simulation and a graphical postprocessor. The simulation evaluates plant designs, equipment trade-offs and yard operating policies. The results are then transmitted to a microcomputer where the simulated operations in the terminal are replayed on a graphics monitor. This computer animation makes it easier to present and understand simulation results. The model was used to study equipment trade-offs at CN's Toronto container facility under projected increased traffic levels.

The User's Manual describes the model development and its main features, as well as giving detailed instructions on how to use both the simulation and the graphical postprocessor.

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17. Résumé

Le Modèle de simulation pour terminaux à conteneurs permet d'étudier sur ordinateur les principales opérations d'un terminal intérieur à conteneurs: arrivée, déchargement, chargement et départ des trains, entreposage des conteneurs acheminés par trains ou par camions, ramassage des conteneurs par les clients. Le modèle est exécuté à l'aide d'une simulation en traitement par lots et d'un postprocesseur graphique. Le programme de simulation sert à évaluer divers aménagements d'installations, matériels et méthodes d'exploitation des triages. Les données de l'analyse sont transmises à un micro-ordinateur qui reproduit les opérations simulées sur une unité d'affichage graphique. Cette animation sur ordinateur facilite grandement la présentation des résultats et leur compréhension. Au terminal à conteneurs du CN, à Toronto, le présent modèle a permis d'étudier plusieurs schémas d'utilisation du matériel en vue de répondre à l'accroissement prévu du trafic.

Le manuel destiné aux utilisateurs explique l'évolution du modèle et décrit ses principales caractéristiques. Il énonce aussi le mode d'utilisation du programme de simulation et du postprocesseur graphique.

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SUMMARY

Intermodal movement of goods over road and rail has become an increasingly attractive method of transportation in recent years. At CN, the increased workload has put a great strain on the existing plant and equipment. Improvements to container terminals involve large capital expenditures. Therefore, each alternative must be carefully evaluated before a final decision is made. A computer simulation is an excellent way of analysing and comparing design alternatives.

The Container Terminal Model (CTM) is a computer simulation of the major operations in an inland container yard. It was developed by Canadian National Railways' Department of Operational Research and Industrial Engineering and partially funded by the Transportation Development Centre (TDC) of Transport Canada.

The model has been developed to aid engineers and transportation planning analysts in the design of new container terminals and in the modification of existing ones. The model consists of two parts: a computer simulation of the intermodal terminal operations, and a graphical postprocessor. The simulation can evaluate various plant layouts, equipment trade-offs and yard operating policies.

The results of the simulation can then be replayed by the postprocessor, animating the major operations in the terminal. A graphical display of simulation output is a vastly superior way of presenting simulation results than previous methods. Rather than reading large volumes of statistical analysis and event logs, the user can now watch the simulated moves as they were processed in the model. Animation makes it much easier for the user to understand the model's logic, assumptions, and results.

A video presentation of the CTM is available from the TDC. This is an effective way to describe the model's features to interested parties. The video focuses on the animation of the postprocessor.

This report describes the steps taken in the development of the model. Chapters 4 and 5 are detailed guides to using the simulation model and the graphical postprocessor, respectively. To test the model's usefulness as a tool to improve the cost effectiveness and efficiency of terminal operations, the CTM was used in a study of CN's CONPORT terminal. The study and the conclusions drawn from use of the Container Terminal Model are described in the final chapters.

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1. INTRODUCTION

In Canada, the transportation of goods in containers and trailers forms a significant portion of the total domestic and international traffic. Intermodal movement, where the long haul is over rail, is expected to become increasingly attractive compared to a straight highway haul as energy costs continue to climb. In such a move, the container or trailer passes through at least two terminals where it switches between rail and another mode such as ship or highway. It is important, therefore, to design intermodal terminals with the objective of reducing resource requirements and decreasing the time spent within the terminal, so as to make rail transportation even more cost efficient.

The design of terminals and analysis of equipment requirements has, in the past, been accomplished through manual simulation. However, a computer simulation improves the quality of the analysis by encompassing more detail than is feasible in a manual version, enabling a greater number of alternatives to be examined within a reasonable time span. The wealth of detail produced by a simulation can also be one of its major problems. Unless the information produced by the simulation is easily understandable, the validity of the model may be questioned and users will be reluctant to accept its results. This project has developed an alternative way to study detailed simulation results, which eliminates the difficulty.

CN Rail's Operational Research group, in cooperation with the Transportation Development Centre (TDC) of Transport Canada, has developed a computer simulation of inland container terminals which incorporates computer animation. The Container Terminal Model (CTM) can be used to test terminal design alternatives and changes in the operating procedures. The model consists of a batch computer simulation, and an animated replay. The simulation is parameter-driven and the resulting log of events is transmitted to a microcomputer where each event is displayed on a graphics screen.

The use of state-of-the-art computer technology such as the graphical postprocessor is a key feature in the CTM. The easily understood graphical displays greatly facilitate the transfer of the model results to improvements in terminal operations in two ways. The postprocessor improves the quality of model verification and validation, and it also gives the user more confidence in the results, since he can see how they were determined.

2. MODEL OVERVIEW

2.1 Yard Layout and Resources

Inland container terminals present complex queueing problems. They vary in the geometric layout of physical plant, their size, the equipment used and the operating strategies. However, all facilities have certain elements in common.

Every terminal must contain rail tracks (sidings), which are accessible from the parent rail yard. The number of tracks and their function (loading/unloading) varies among terminals.

The containers themselves are moved about the yard by means of lifting equipment. The two major categories of machines are:

1) gantry cranes - Straddle a track and its adjacent trackside storage; lift containers from above.

2) front loaders - Travel throughout the yard; lift containers from the side.

Storage takes up most of the area in inland container terminals. The containers are stored in rows, often stacked up to three high. The storage areas can be found near the tracks or in remote parts of the terminal. Usually, containers are segregated by size and whether they are loaded or empty. Empty containers are further segregated by owner and container type.

Every intermodal yard has a gate office where the container pickups and deliveries are processed. Each terminal has its own procedures and paperwork.

Each terminal has access to switching engines for pulling cuts of flatcars. These are usually part of the equipment resources of the parent yard, but their use may be dedicated to the intermodal terminal.

The trucks and chassis that transport the containers to and from the container terminal do not necessarily belong to the railways. They may, in fact, be owned by the container lines and the freight forwarding companies.

2.2 Yard Operations

Inland container terminals are important resources in the transport of containers across Canada. In many cities, the container facilities and piggyback facilities are combined, sharing lifting equipment and track. This project deals only with container handling.

A container arrives at an inland container terminal either by train or by truck. The train could have originated at another inland terminal or at a port terminal where the containers arrived by ship. Containers arriving by truck will either be sent out on an outbound train or stored in one of the on-site storage stacks.

The container cars arriving by train have previously been switched at the terminal's parent rail yard. One or more lifting machines are assigned to unload all the containers. They are removed from the flatcars, one by one, and placed in the appropriate storage area or directly on a chasis.

Containers arriving by truck pass through the terminal gate where their paperwork is processed. The driver then proceeds to the assigned yard destination, either the track (if the container is departing on an outbound train) or to storage (if the container is empty). The container is removed from the truck chassis and positioned by a lifting machine.

Containers leave the yard either by rail or by road. The containers which have been loaded onto flatcars leave the yard when the track is pulled. The flatcars will pass through the parent yard where they may be switched onto a larger train. Containers that arrived by train leave the terminal by truck. Drivers from the container lines or the railways go to the appropriate storage area where they are met by a lifting machine. The lifter removes the container from its place in the storage stacks (which could involve the movement of other containers stacked on top of it) and places it on the truck chassis. The driver proceeds to the gate to sign release forms. Drivers may also arrive to pick up empty containers stored in the terminal's long term storage.

In many cases, these pickups and deliveries are combined in a single trip to the container yard. A truck arrives with a loaded container which will leave on an outgoing train, for example, and picks up another container from storage which will be delivered outside the terminal.

2.3 Scope of the Model

One of the purposes of the project was to develop a model that could handle the variations in container terminals. To achieve this, the user describes the terminal in the input, entering parameters that directly affect the facilities and operations.

The simulation follows a container from its arrival at the gate or on a train placed on a track, to its departure through the gate or on a train leaving a track.

The graphical postprocessor shows a schematic of the yard and replays movements of loading machines, containers and trucks throughout the terminal.

3. PROJECT DEVELOPMENT

3.1 Simulation

3.1.1 Model Development Approach

The objective of this part of the project was to develop, validate and test a computer simulation model that could be used to improve the cost effectiveness and efficiency of inland container terminal operations. A key element in developing large simulation models is the selection of the programming language.

The programs were written in the simulation language SIMSCRIPT II.5. This language is ideally designed for this task since it allows a high degree of flexibility in its modelling and report generation features. As well, CN has experience in using it to develop simulation models. Some models previously developed in Simscript at CN are: Piggyback Terminal Model, Route Capacity Model, the Trip Inspection Model, and the Coastal Simulation Model.

The simulation runs in a batch mode; that is, once the parameters for a particular scenario are entered in an input file, the model is run to perform the simulation and to generate the resulting statistical reports without any user intervention.

The simulation was developed in a phased approach, gradually increasing the complexity of the model in each phase.

3.1.2 Simulation Project Phases

Seven phases were identified as milestones to project completion.

Phase I - Survey of Existing Terminals

We studied machine operating decisions and terminal operations at CN's container facilities in Montreal and Toronto. With the information collected, the level of detail required for the model was determined.

Phase II - Design of Model

The formal representation of the model was designed after the survey was completed. This included the definition of model inputs, outputs and structure, ie., role of individual submodules and their interaction.

Phase III - Simplified Model

CN developed a working model in terms of train placement and removal on track and machine movement logic. Storage control and patterns of pick-up and arrival of containers and trailers were kept simple. This phase included the necessary report generation.

Phase IV - Refined Model

Using the model developed in Phase III as a base, the storage control logic, patterns of container and trailer arrival and departure, etc. were refined, and the machine dispatching and outbound train blocking sections were enhanced.

Phase V - Verification/Validation/Documentation

Verification included debugging of the model to ensure that its logic followed the design. Several enhancements were made to the model at this time.

Validation involved using the model on data from an existing terminal. Model calibration was based on a time study of sample operations in CN's Conport terminal. The parameters and control logic were adjusted where necessary to reflect actual operations.

The model programs were documented for the purpose of future maintenance.

Phase VI - Applications

The model was used to analyze operations in CN's container terminal at Toronto. This terminal has 5 loading tracks, 4000 T.E.U.'s storage, 2 gantry cranes and 9 front-loaders. The CTM was used to study the effect of expected increased traffic levels on machine utilization. The following alternatives were studied:

a) Addition of 1 front loader
b) Addition of 2 front loaders
c) Addition of front-loaders with changes in machine schedules and shifts to cover peak daily periods.

In this case, the model helped CN to evaluate the additional machine requirements to handle increased container traffic levels.

Phase VII - Final Report/Video Presentation

The final report phase involved preparing this User's manual with complete details on the usage and scope of the model.

Also, a presentation of the model was produced on video cassette, highlighting the graphical postprocessor. This is an effective means of describing the model's capability to interested parties. The video cassette is available from the TDC.

3.2 Graphical Postprocessor

3.2.1 Project Phases

The development of the postprocessor was divided into five phases:

Phase 1 - Hardware/Software Selection

A review was made of various micro and mini-computers which possessed the necessary memory, storage capacity, communications package and high speed arithmetic processor. The Intel 330A micro computer was selected as best meeting these requirements. This computer uses the XENIX multi-user operating system and has a "C" compiler. "C" was chosen as the programming language due to its ease of use, speed of model development and its transportability to many other types of computers.

In addition, a Raster technologies model ONE/20 display controller was chosen to produce the graphics display. To make the user interface easy to use, a digitizer tablet with cursor (mouse) was selected to replace a standard keyboard for entering commands.

Phase II - Preliminary Design

The design phase determined the details of what would be shown in the replay. After deciding on the scope of the replay, a description was made of each event record that would be produced for the log file by the simulation model.

Phase III - Implementation

The programming of the postprocessor was divided into two modules (programs). The first module initializes the display, reads the selected logfile, and allows the user to adjust the paths to any configuration. The final module actually reads in the events from the logfile and drives the user-controlled dynamic display.

Phase IV - Refinements/User Testing

Considerable improvements were made to the programs in this phase. Feedback was obtained from the users of the replay and, where possible, their suggestions were incorporated into the model.

Phase V - Project Evaluation

The final project phase involved the evaluation of the graphics replay and the development approach. Since this type of simulation output is relatively new and a dramatic change from previous statistical reports, its impact on the testing of the simulation and the ultimate acceptance of the model by the user had to be thoroughly assessed.

4. USING THE SIMULATION

4.1 Hardware/Software Requirements

The simulation model was developed on an IBM S/370 series machine with a TSO/SPF system. The model and the output reports are written in SIMSCRIPT II.5, a powerful modelling language. CN used the most recent version of the IBM compiler, V9.3, for model development.

The information required to run the simulation is entered at a computer terminal by means of formatted screens. Statistical Analysis Systems Inc. software (SAS and SAS/FSP) was used to design the formatted screen and to write the model preprocessor. If the model is being run on a system where SAS is not available, the data may be entered directly onto a sequential data file which can be read by the SIMSCRIPT program.

The menus that are displayed at the TSO terminal are written using SPF Dialog (available on IBM machines with TSO/SPF). The selection of a particular option causes a Clist (command list) program to be executed. The Clists include such information as the data set name of the SAS library and the load module library. The SPF dialog software is only used to design the menu screens. Therefore, users who do not have access to SPF/TSO may replace the panels with series of 'prompts' (write/read) in the Clist programs.

4.2 Preprocessor

Data entry is the principal contact that a user will have with the model. For that reason, the method used to create the input files will have a significant impact on the acceptance of the simulation by the user. It is also important that the user become very familiar with the input file and the related procedures.

SAS/FSP (Full Screen Product) facilitates data entry through formatted terminal screens. The screens indicate where and how the data should be entered. SAS/FSP is also capable of some error checking as the data is being typed in.

There are four data files, each of which can be edited separately. They are:

1. Plant layout and system parameters
   - duration of simulation, gathering of statistics, level of detail in the output
   - storage capacity and characteristics
   - gate processing time
   - average truck speed and flatcar length per TEU (twenty-foot equivalent unit)
   - positions of each gate, storage and track are given in coordinates on a global grid of the yard layout.

2. Machine definitions
   - characteristics of the machine(s)
   - restrictions on its use
   - times to complete certain activities
   - shift duration and break schedules.

3. Train schedules
   - arrival and departure times
   - mean number of containers
   - assigned track
   - destination block data for outbound trains
   - number of corresponding empirical distribution.

4. Empirical distributions
   - arrival time in yard for outbound containers
   - customer pickup day for inbound containers
   - daily arrival pattern of inbound container pickup
   - train configuration (types of containers aboard)
   - empty container arrivals and departures in yard.

4.2.1 Plant Layout and System Parameters

This section is divided into five separate screens. The first screen (figure 1) contains the general system parameters. Lines 1-4 deal with the actual simulation run, while lines 5-7 are general yard parameters which will affect the entire simulation. Run I.D. is a character variable giving a user-specified name for that computer run. The duration of the simulation is measured in days. The time at which the simulation begins calculating statistics is entered as hours after the start of simulation. The random number stream variable is a value from 1-9 used to initiate the random number generator (Refer to SIMSCRIPT II.5 documentation for further information on the random number generator).

Car length/TEU is the length of track needed to accomodate a flatcar holding a single container TEU. The average speed of the customers' trucks in miles per hour is entered in the truck speed field. Finally, the trace specification is a series of optional parameters that allows the user to specify the level of detail and the type of messages to be printed in the simulation log.

The first part of the container yard layout is entered on the track definition screen (figure 2). The user must specify the coordinates (in feet) of the track on an (x,y)-grid of the yard. Each track is named in the track I.D. These values indicate the start and end positions of the track in the yard and are used to determine the track length. The average time to switch a cut of flatcars is also entered on this screen.

Figure 3 shows the gate definition screen. The number of servers may vary during a work day, as is indicated in the first table. It is compulsory to enter the average time needed to process a single container, as well as the standard deviation of the processing time. The gate's position in the yard is indicated by the x and y coordinates (given in feet from the lower left-hand corner of the yard plans). The user also specifies which days of the week the gate is opened to customers.

The storage definition screen (figure 4) has the following fields, plus a character variable for the storage name. The initial units are the number of TEU's in storage at the beginning of the simulation. The user can limit the types of containers allowed in each area. Container length may be either 20 ft. or 40 ft. The containers may be either loaded (L) or empty (E). Also, a storage area may contain either import/export (I) or domestic (D) containers. The storage layout is defined by the height of the stacks, the length of the rows in TEU's and the number of rows.

The storage boundaries (figure 5) are given in x,y coordinates that cut diagonally across the storage area. The recommended practice is to enter the lower left-hand coordinates first, followed by the upper right-hand coordinates. The user also indicates if the rows of containers in storage run horizontally or vertically through the storage area.

4.2.2 Machine Definitions

The following information is required for each machine. The machine must have a name and a single character indicating its type as either a crane (C) or a loader/lifter (L). The machine speed should be the average speed of the machine in the terminal (M.P.H.). Shifts are defined by the beginning hour and the ending hour of the daily shift. Working days are given in a series of numbers from one to seven. The work breaks are described by indicating the number of breaks in a daily shift, the average length of each break and the standard deviation of the length of the break (figure 6). The second panel of the machine definition (figure 7) contains the times each machine requires to perform the various loading and unloading activities. It is also possible to assign a machine to work in certain parts of the yard (figure 8). Each assigned location is entered as a text string, starting with T for track or S for storage, followed by the I.D. number of that track or storage area. The user may also place restrictions on the size and contents of containers that the machine can carry. Machines may handle only loaded containers (L), empty containers (E) or all types (A).

FIGURE 1

SYSTEM PARAMETERS

Run I.D. : _____

Duration of Simulation : _____ DAYS

Start Simulation Statistics : _____ HR

Random Number Stream : _____ (1-9)

Flatcar Length / TEU : _____ FT

Average Truck Speed : _____ MPH

TRACE Specification :

Start Time	Duration	Detail
_____	_____	_____
_____	_____	_____
_____	_____	_____
HR	HR	1234567890

If tracing is desired,
select a value from 0-9 for each container.

CATEGORIES :

1 - containers
2 - "
3 - "
4 - inbound trns
5 - outbound trn
6 - machines
7 - "
8 - mach.file
9 - storages
10 - graph log

FIGURE 2

TRACK DEFINITION

	I.D.	TRACK BOUNDARIES Coordinate x	y	Coordinate x	y
1	____	____	____	____	____
2	____	____	____	____	____
3	____	____	____	____	____
4	____	____	____	____	____
5	____	____	____	____	____
6	____	____	____	____	____
7	____	____	____	____	____
8	____	____	____	____	____
9	____	____	____	____	____

NOTE : The coordinates are measured in feet from the origin

Average Switching Time : _____ MIN

F I G U R E 3

GATE DEFINITION

	Hour Shift Ends	Number of Servers
(Starting Hour 00:00:00)	_____	_____
	_____	_____
	_____	_____
	_____	_____
	_____	_____

Gate Processing Time : Mean - _____ MIN St.Dev.- _____ MIN.

Gate Coordinates : x - _____ FT y - _____ FT

Days of Week Gate is Opened : ------ (1-7)

F I G U R E 4

STORAGE AREA DEFINITION

Name	Initial Units	Container Specifications LENGTH	LOADED?	IMPEX?	LAYOUT No. Levels	No. Rows	Row Length
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
_____	_____	___	-	-	_____	_____	_____
	TEU	20/40	L/E	I/D			TEU

F I G U R E 5

STORAGE BOUNDARIES

	Coordinates of Diagonal LOWER x	LEFT y	UPPER x	RIGHT y	Direction of Rows in Storage
1	____	____	____	____	-
2	____	____	____	____	-
3	____	____	____	____	-
4	____	____	____	____	-
5	____	____	____	____	-
6	____	____	____	____	-
7	____	____	____	____	-
8	____	____	____	____	-
9	____	____	____	____	-
10	____	____	____	____	-
11	____	____	____	____	-
12	____	____	____	____	-
					H/V

F I G U R E 6

MACHINE SHIFT DEFINITION

Machine Name	Mach Type	Travel Speed	S H I F T Start	End	WORKING DAYS	B R E A K S No.	Length	St.Dev
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
________	-	____	____	____	_____	____	____	____
	C/L	MPH	HR	HR	(1-7)		HR	HR

FIGURE 7

MACHINE ACTIVITY TIMES

Mach I.D.	TRUCK Load	TRUCK Unload	FLATCAR Load	FLATCAR Unload	STORAGE Pickup	STORAGE Place
1	____	____	____	____	____	____
2	____	____	____	____	____	____
3	____	____	____	____	____	____
4	____	____	____	____	____	____
5	____	____	____	____	____	____
6	____	____	____	____	____	____
7	____	____	____	____	____	____
8	____	____	____	____	____	____
9	____	____	____	____	____	____
	MIN	MIN	MIN	MIN	MIN	MIN

FIGURE 8

MACHINE ASSIGNMENTS

Mach. I.D.	Assigned Locations			Types of Containers Handled: CONTENTS	SIZE
1	____	____	____	-	____
2	____	____	____	-	____
3	____	____	____	-	____
4	____	____	____	-	____
5	____	____	____	-	____
6	____	____	____	-	____
7	____	____	____	-	____
8	____	____	____	-	____
9	____	____	____	-	____
	Tnn/Snn			E/L/A	20/40

4.2.3 Train Schedules

Train schedules are divided into inbound trains and outbound trains. The data file has a single screen for each type.

The outbound train definition (figure 9) includes the identification number of the train, the mean number of containers/train and its standard deviation. The preferred track indicates the assigned track for each destination block. Each block must be assigned its own track, but several blocks could rest on the same track. The user must include the amount of time before cut-off that the flatcars can be placed on the track (for loading), the cut-off time after which no further containers can be loaded, and the time of departure from the container terminal. The departure day number is a series of numbers giving the days of the week on which this train will depart. Each destination block of the outbound train has a probability distribution number associated with it.

The inbound train definition (figure 10) also includes the identification number of the train, the mean number of containers/train, its standard deviation and the assigned track for that train. If the train is to be unloaded on several tracks, each section should be entered as a separate train. The time parameters are the delay time between the train's arrival and the beginning of the unloading process, and the train's arrival time in the yard. Each train has a probability distribution associated with it and a series of numbers giving the days of the week on which this train will arrive.

4.2.4 Empirical Distributions

Each element in the inbound train distribution (figure 11) represents the fraction of the total containers for that train which will depart the yard during the specified interval. The time intervals are given in days after train arrival. The start of the first interval is assumed to be at train arrival. The container departure times are generated uniformly within the specified time interval, unless the user has entered the distribution number of the related daily distribution. In that case, the container departure hour is generated using the daily distribution.

This screen also allows the user to specify the train makeup, i.e. the types of containers on that train. The user gives the percent of the trains' containers which are import/export (IMPEX) and domestic. Both of these groups may be further broken down into the percentage of containers which are loaded versus those which are empty, and the ratio of 20 ft. to 40 ft. containers.

The daily arrival pattern of customers entering the yard to pick up inbound containers is entered on a separate screen (figure 12). This data permits the user to emulate the yard hours of operation and its peak hours within the working day.

The distribution number referenced in the train schedules is the observation number found in the upper right-hand corner of each screen. This value is automatically updated by the computer.

The outbound train distribution is very similar to the inbound screen (figure 13). The time intervals are given in hours before pull time, with the limit at pull time. Corresponding to each interval is the fraction of outbound containers that will arrive in the yard during that period. The arrival times are generated uniformly within the time interval. Since each destination block may have its own distribution, the first line contains the percentage of the train that is described by this distribution. The lines describing the block configuration are identical to those found on the inbound train screen.

The final input screen contains information on the daily movements of empty containers (figure 14). Each element of the distribution gives the actual number of arrivals and of departures of empty containers in the yard. The time intervals are hours in the day with the earliest interval beginning at time 00:00:00. The user must also specify the days of the week for which this distribution is applicable, the ratio of 20 ft. to 40 ft. empty containers and the ratio of IMPEX to domestic containers.

FIGURE 9

OUTBOUND TRAIN DEFINITION

Train I.D.	No of Cont MEAN	S.DEV	Track/ Block	Time Spent Trk Side	Cut Off	Pull Time	Departure Day nos.	Dist'n no. of each Dest'n	Block
				NO.HR	NO.HR	HR.DAY	1-7		

FIGURE 10

INBOUND TRAIN DEFINITION

Train I.D.	No of Cont MEAN	S.DEV	Pref. Track	Delay Time	Arrival Time	Dist'n no.	Arrival Day No.
				No.HR	HR.DAY		1-7

F I G U R E 11

INBOUND TRAIN DISTRIBUTION - CUSTOMER ARRIVAL TIMES

Number of Related Daily Customer Arrival Distribution : ———

Days After Train Arrival (train arrival - day 0)	Fraction of Containers Picked up During Day
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———

Distribution of Containers on Train
%IMPEX : ———
%Load : ———
%20 ft: ———
%DOMESTIC
%Load : ———
%20 ft: ———

F I G U R E 12

DAILY CUSTOMER ARRIVAL DISTRIBUTION

FOR CONTAINERS ARRIVING ON INBOUND TRAINS

Hour of Day	Fraction of Containers Leaving Yard
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———

FIGURE 13

OUTBOUND TRAIN DISTRIBUTION - CONTAINER ARRIVAL TIMES PER DESTINATION

% Train in this Destination Block : ———

Hours Before Pull Time (1st. period starts at pull time)	Fraction of Containers Entering the Yard During Specified Period
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———
———	———

Distribution of Containers on Block
%IMPEX : ———
%Load : ———
%20 ft: ———
%DOMESTIC
%Load : ———
%20 ft: ———

FIGURE 14

EMPTY CONTAINER DISTRIBUTION

Number of Containers Processed Daily

Hour	Yard Arrivals	Yard Departures
———	———	———
———	———	———
———	———	———
———	———	———
———	———	———
———	———	———
———	———	———
———	———	———
———	———	———
———	———	———

DAYS of WEEK : ———
%20 ft : ———
%IMPEX : ———

4.3 Simulation

4.3.1 Container Terminal Resources Modelled

The CTM focuses on the following resources in the yard :

1. Gate
   - processes paperwork for each container entering and leaving the yard;
   - hours and days of operation can be specified;
   - can have multiple servers at the gate.

2. Tracks
   - divided into spots to accomodate the flatcar space required for each container and adjacent trackside space.

3. Storage
   - multi-level area for storing containers;
   - containers can be grouped by size, load vs. empty, and IMPEX vs. domestic;
   - each storage divided into spots uniquely defined by row, column, and permitted stacking height.

4. Machines
   - used to load/unload containers from storages/ trains/chassis and to move containers within the yard;
   - can be assigned to specific work areas, shifts, and types of work;
   - can be either a front or side loader, or a gantry crane.

4.3.2 Processes

The SIMSCRIPT program has three principal elements. They are:

1) PREAMBLE - description of each model element used;
2) MAIN - the simulation initializer;
3) PROCESS - sequence of interrelated events separated by time lapses.

In the CTM, there are nine major processes, which are further subdivided into subroutines and sub-processes.

4.3.2.1 TRACE

The TRACE process regulates the printing of a simulation event log (section 4.4.3) and of certain output files (see sections 4.5.2 and 4.5.3). The user controls the types of events to be entered in the log, and the time span over which the log will be printed (in terms of simulated time).

4.3.2.2 Machine Operator

There is an OPERATOR for each machine. Initially the machine will be located at the gate (except for cranes which are located at a track). At the beginning of each daily shift, the OPERATOR activates the machine, making it available for work. The process also schedules the breaks during the day. If there is any work still assigned to the machine at the end of its shift, the task is released and returned to the general task list.

This process runs for the duration of the simulation.

4.3.2.3 Gate Operator

Gate servers work in shifts, with a variable number of staff working each shift. The OPERATE GATE process schedules the gate shifts each day.

This process also runs for the duration of the simulation.

4.3.2.4 Outbound Train Arrival

This process is activated for each outbound train scheduled to depart the yard during the simulation. It commences shortly before the arrival of the empty flatcars on the track(s). Each destination block of the outbound train is assigned to a track. Several blocks may be placed on the same track.

If the previous day's identical train has not finished loading, the simulation is stopped because of the abnormal congestion on the track. If all is well, the

simulation first activates any containers that are already in the yard (storage) and which are scheduled to go out on this train. These containers will be moved to trackside by loading machines.

When the empty flatcars arrive on the track, the containers already at trackside will begin loading. The GATE ARRIVAL process controls the placing of the containers on the train during loading.

At cutoff time, the process prepares the train for departure. Any containers arriving in the yard after that time are brought directly to storage. The train is pulled at the scheduled time, or when the work-in-progress at cutoff time is completed.

4.3.2.5 Load Container

Every container that is assigned to an outbound train has a GATE ARRIVAL process. It is activated when the container arrives in the yard.

The container is first processed at the gate by one of the gate servers. There, it receives its destination in the yard, which is either a track or a storage area. If the train is currently loading and has room for the container, the customer drives directly to the track where the container is placed trackside. When a flat car spot becomes available, the container is loaded on the train. If the container arrives after cut off time, the customer drives the container to the appropriate storage area where it is stored until another train with the same destination begins loading at the same track.

If the container is loaded on the last empty flatcar and cutoff time is still far away, the GATE ARRIVAL process calls the "pull block" routine. This routine switches out the full flatcars, searches for pending requests and switches in a new cut of empty flatcars to continue loading that outbound train.

The process ends with the successful loading of the container on the outbound train.

4.3.2.6 Inbound Train Arrival

Inbound train handling begins with the arrival of the train in the container terminal, which activates the INTRAIN ARRIVAL process.

If the previous train of the same name has not finished unloading, the simulation is stopped because of the abnormal congestion on the track. If all is well, the process first generates the containers which are arriving with the train.

As much of the train as possible is placed on the track (The remainder of the train is assumed to be on a storage track not modelled by the simulation). The UNLOAD process triggers subsequent placing of container-filled flatcars on the track.

INTRAIN ARRIVAL ends when the last container of that inbound train is unloaded. Customers may continue to pick up the containers in storage until all containers have left the yard, or the simulation is ended.

4.3.2.7 Unload Container

Every container that is assigned to an inbound train has an UNLOAD process. It is activated when the train arrives in the yard.

The container is removed from the flatcar by a loading machine or a gantry crane. If the customer is already in the yard (early pick-up time), the container is placed directly on the truck chassis by the machine.

Otherwise, the container is carried to the appropriate storage by the machine where it is placed in a vacant spot to await pickup. At pickup time, the customer drives to the storage area and the container is placed on the truck chassis by a lifting machine or crane. The container is then processed at the gate and leaves the terminal.

If the container being unloaded from the train is the last one on that cut of cars, the empty flatcars are switched out. If there are more containers waiting, the next cut is brought in to be unloaded.

4.3.2.8 Empty Arrival

Concurrent with the arrivals and departures of trains at a terminal is the movement of empty containers in and out of the yard. Container terminals provide storage space for the customers' empty containers. Each movement of an empty container in or out of the yard utilizes machinery and the gate.

The EMPTY process is activated each time an empty container is brought into the yard by a customer. The container is processed at the gate and then driven to the appropriate storage area. It requests a machine to unload the container from the truck and to place it in the stacks.

4.3.2.9 Request Empty

A customer's request for an empty container triggers the arrival of a truck at the appropriate storage. The container chosen from storage is the one closest to the storage entrance. A lifting machine picks up the closest container and places it on the truck chassis. The truck drives to the gate where the container is processed before leaving the terminal.

4.4 Output

Simulation output allows a user to evaluate the performance of a container terminal, given the plant and traffic specified in the input. Statistical reports, activity logs and graphs can all be used to present the information.

4.4.1 Performance Indicators

The CTM calculates such performance indicators as customer service time, load time and delays on outbound trains, unload time and number of switches on inbound trains, container terminal traffic levels, machine utilization by activity and location, track utilization, storage utilization and gate utilization.

4.4.1.1 Gate Report

There are four gate reports generated by the container terminal model. The gate statistics report contains the mean and standard deviation of the gate delay, of the interarrival time at the gate and of the length of the gate queue. It also contains the theoretical mean of both the gate delay and gate queue, as well as the maximum queue length. (figure 15).

Three histograms are produced in the gate report (figures 16-18). The first is a distribution of gate inter-arrival times (in minutes). The second shows the percentage of time that the gate queue length is within a certain range. The third histogram displays the distribution of the length of customers' delays at the gate.

4.4.1.2 Track Report

For each track, the simulation produces a histogram of track utilization over time (figure 19). There is also a plot of track allocation which will be described in section 4.4.2.1.

4.4.1.3 Storage Report

The simulation produces a histogram for each storage area, showing the percentage utilization of that storage area over time (figure 20).

4.4.1.4 Container Traffic Report

The container traffic statistics give daily and track totals of container traffic at both the tracks and the gate (figure 21). They are broken down by inbounds versus outbounds and empties versus loads. It also gives the number remaining to load and to unload at the track at the end of each day.

4.4.1.5 Inbound Train Report

For each train I.D., the simulation output shows the number of trains simulated and the

FIGURE 15

GATE STATISTICS

RATIO OF SERVICE TIME TO INTERARRIVAL TIME = 1
GATE QUEUE IS NON STATIONARY... 1.2170

DELAY AT GATE -

MEAN :	1.27 MINUTES
STANDARD DEVIATION :	2.32 MINUTES
THEORETICAL MEAN :	0. MINUTES

INTERARRIVAL TIME AT GATE -

MEAN :	3.29 MINUTES
STANDARD DEVIATION :	5.92 MINUTES

LENGTH OF QUEUE AT GATE -

MEAN :	.39 CUSTOMERS
THEORETICAL MEAN :	0. CUSTOMERS
STANDARD DEVIATION :	1.18 CUSTOMERS
MAXIMUM :	8 CUSTOMERS

FIGURE 16

Distribution of Gate Inter-Arrival Times

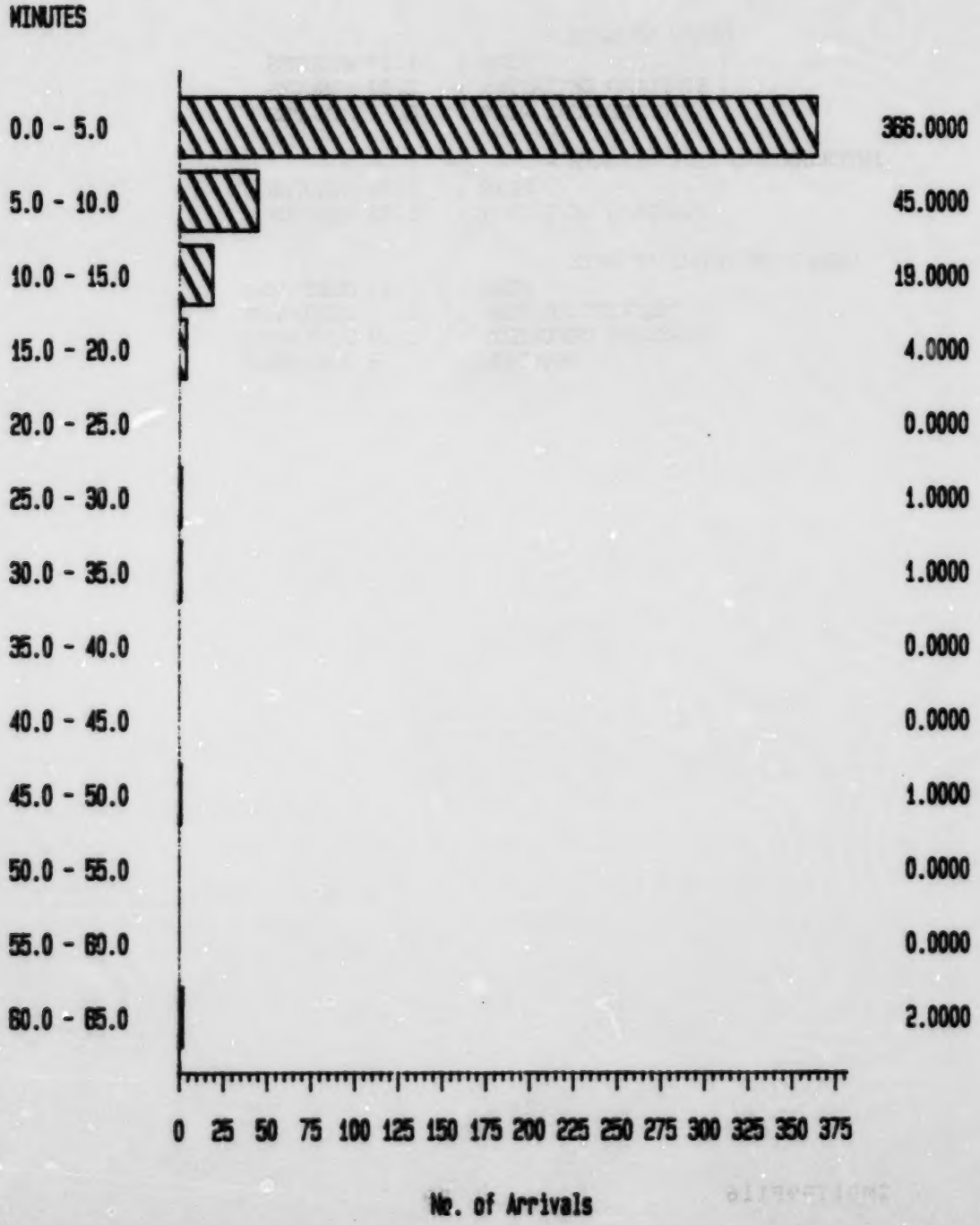


FIGURE 17

Distribution of Gate Queue Length

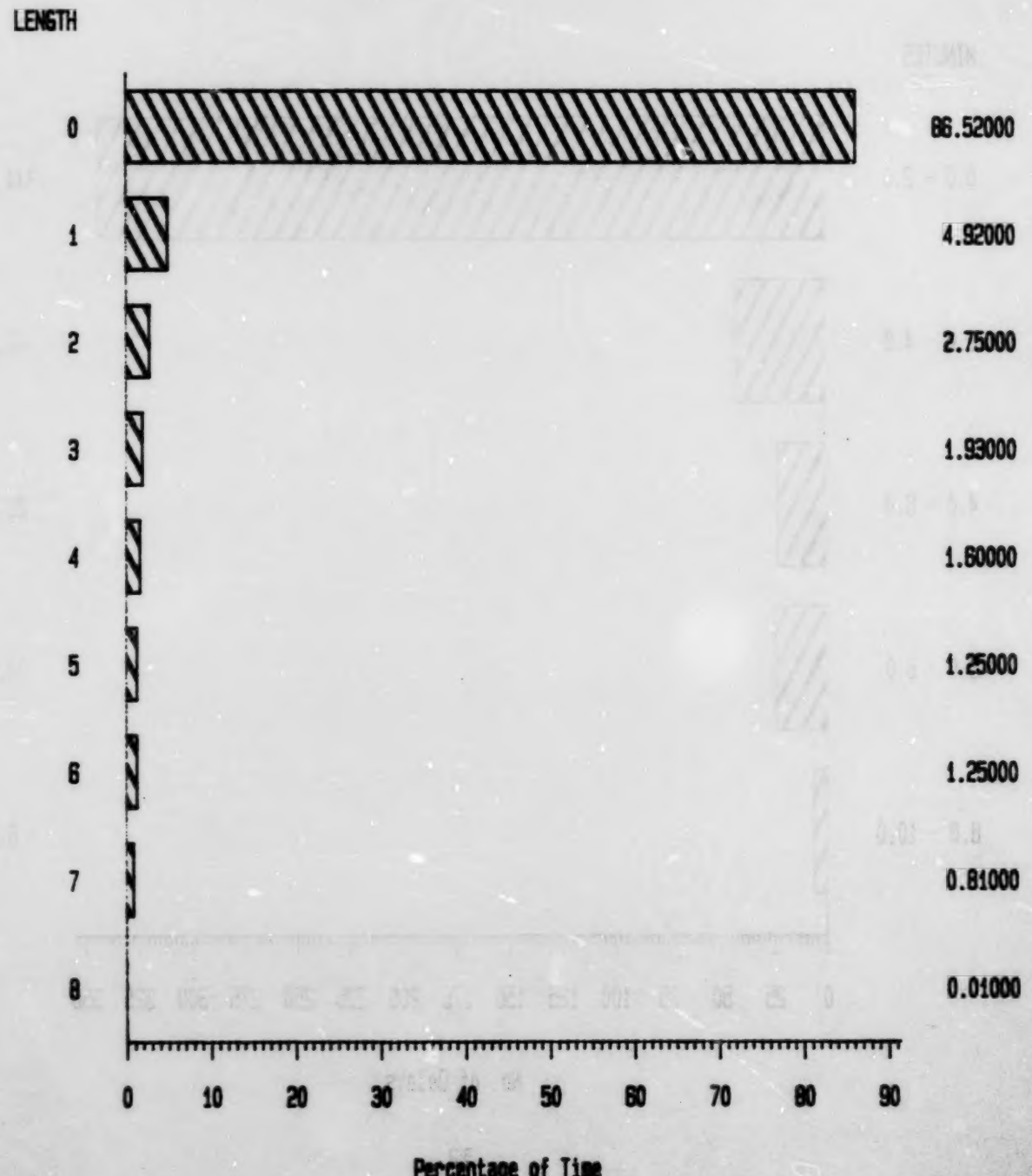


FIGURE 18

Distribution of Gate Delays

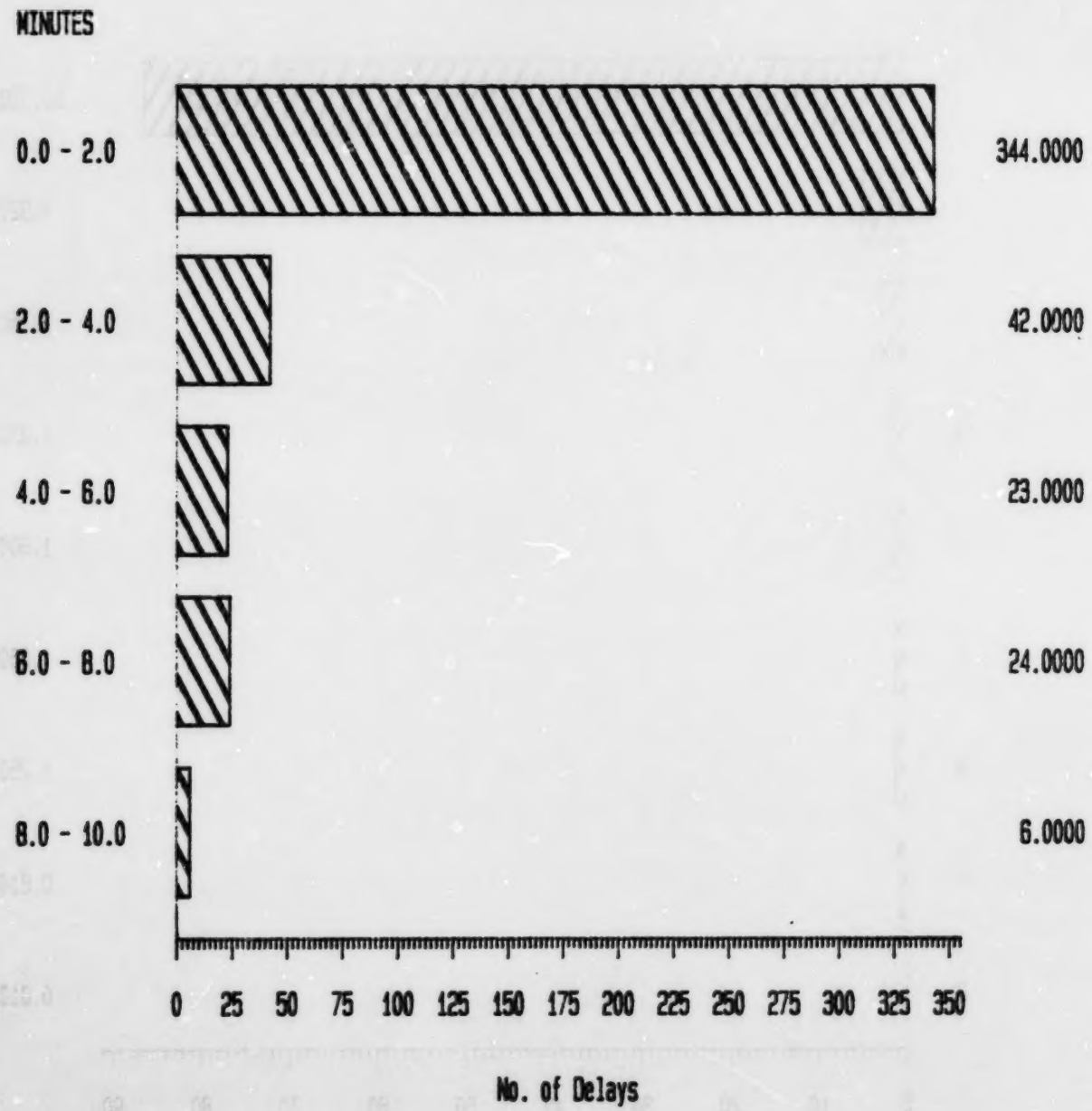


FIGURE 19

Distribution of Track Utilization for Track 1

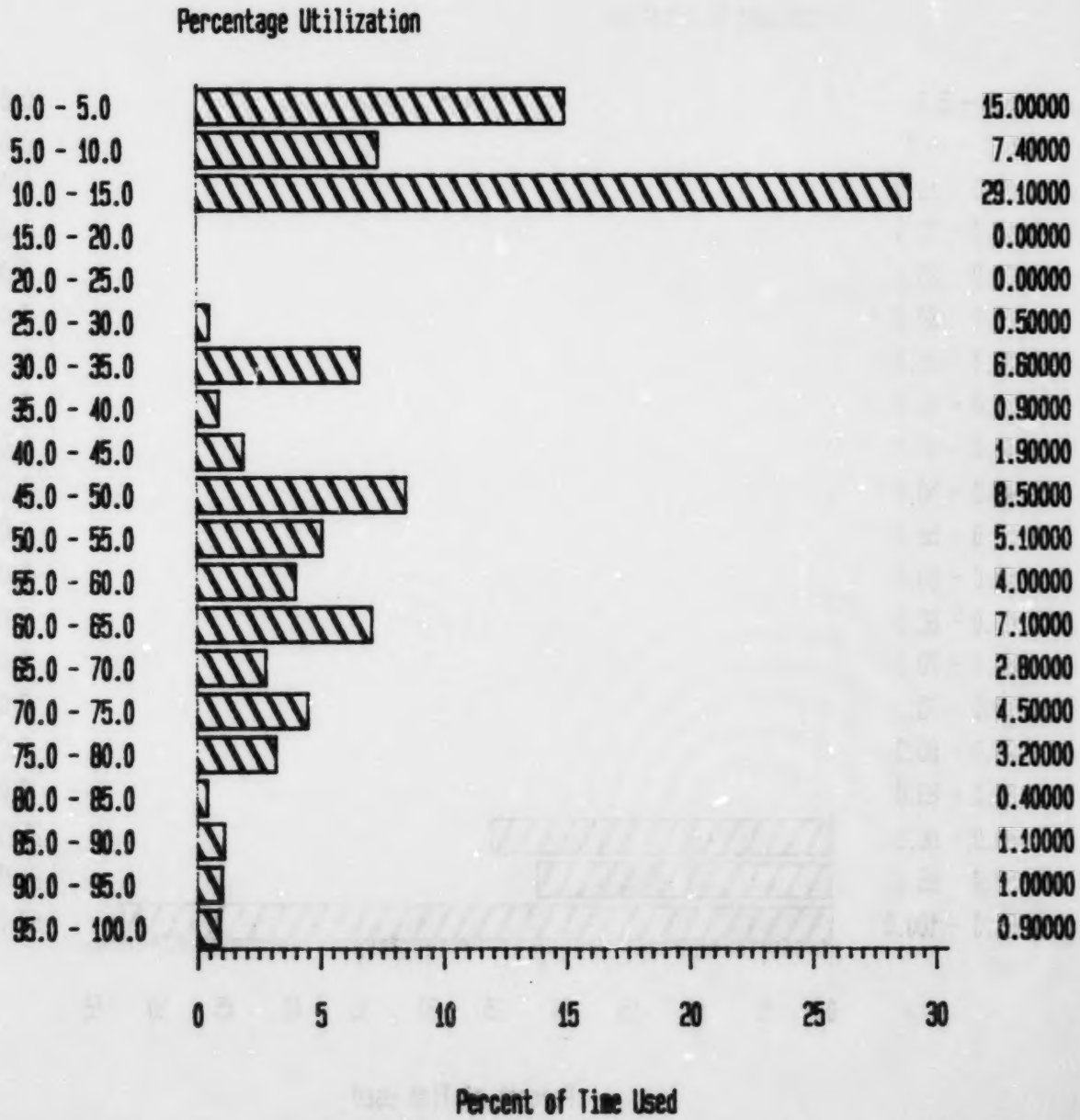
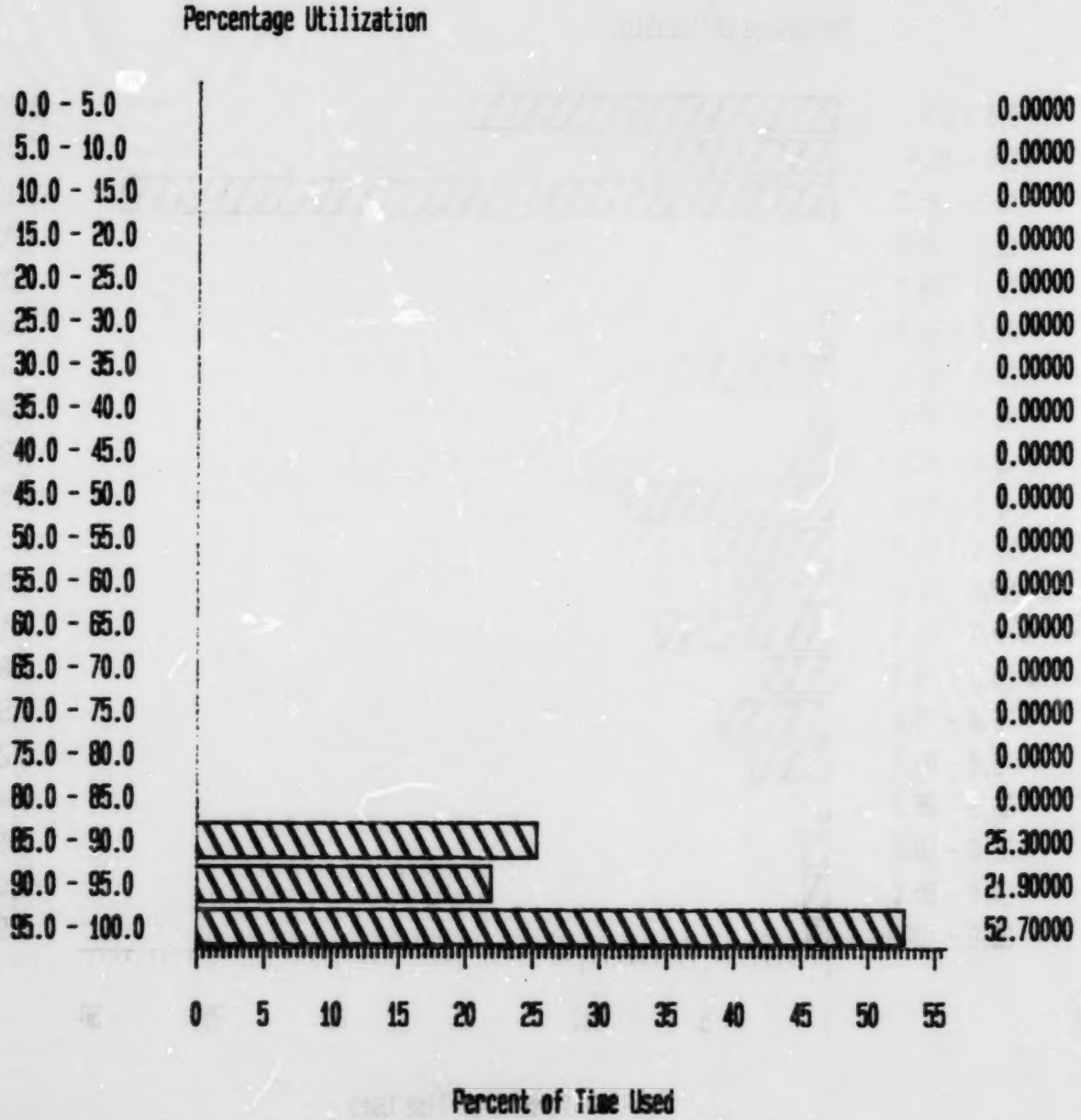


FIGURE 20

Distribution of Storage Utilization for Storage 1



CONTAINER TRAFFIC STATISTICS

ARRIVALS AND DEPARTURES AT TRACKS

DAY	TRACK	NO. INBOUND EMPTIES	NO. INBOUND LOADS	NO. OUTBOUND EMPTIES	NO. OUTBOUND LOADS	NO. REMAINING TO LOAD AT DAY END	NO. REMAINING TO UNLOAD AT DAY END
2							
	1	0	0	10	36	15	0
	2	0	0	20	34	5	0
	4	5	4	0	0	0	0
	5	0	0	9	53	3	0
DAILY MEAN		5.00	4.00	39.00	123.00	23.00	0.
DAILY MAXIMUM		5	4	39	123	23	0
TOTAL		5	4	39	123	23	0

ARRIVALS AND DEPARTURES AT GATES

DAY	GATE	NO. LEAVING YARD EMPTIES	NO. LEAVING YARD LOADS	NO. ENTERING YARD EMPTIES	NO. ENTERING YARD LOADS
2					
	1	99	13	185	142
DAILY MEAN		99.00	13.00	185.00	142.00
DAILY MAXIMUM		99	13	185	142
TOTAL		99	13	185	142

FIGURE 21

number of switches needed to unload the train. The report also contains the mean number of both 20 ft. and 40 ft. containers. Delay statistics describe the amount of time that the container stayed on the flat car before being unloaded. The mean, standard deviation, maximum and per container train unload times complete the report (figure 22).

4.4.1.6 Outbound Train Report

The following information is gathered for each outbound train: the number of trains, the mean number of containers per train and the mean train departure delay. The customer delay statistics include the mean, standard deviation and the maximum delay time (in minutes) that the customer waited to be serviced by a machine. The load time statistics are the mean, standard deviation and maximum time (in hours) it took to load a train, as well as the average number of minutes each container took to be loaded. The report also gives the average and the maximum time each outbound container spent in storage and at trackside before loading (figure 23).

4.4.1.7 Machine Report

For each machine, there are statistics on the percentage of time that a machine spends on each activity and at each location within the yard, as well as daily statistics on the number of containers handled by each machine (figure 24).

4.4.2 Output Files

Several output files are prepared to aid in finding errors in the program and in evaluating the model's logic. The most comprehensive of these files is the event by event description of the model's operations. The user controls the amount of detail specified by the trace specification in the input data, which is described in section 4.3.2.1.

4.4.2.1 Daily Status

At the end of each day of simulation, the model produces a report giving the current status of the storage areas, the tracks and the number of containers in the yard waiting to be unloaded from inbound trains and to be loaded on outbound trains (figure 25).

INBOUND TRAIN STATISTICS

TRAIN NAME	NUMBER OF TRAINS	NUMBER OF SWITCHES	MEAN NUMBER OF CONTAINERS 20'	MEAN NUMBER OF CONTAINERS 40'	UNLOAD TIME (HRS.) MEAN	STANDARD DEVIATION	MAXIMUM	MIN. PER CONTAINER
IT6-NTU	1	1	7.00	13.00	2.15	0.	2.15	5.453
IT6-OTU	1	2	49.00	39.00	11.00	0.	11.00	7.501
IT4-OTU	1	3	79.00	61.00	11.96	0.	11.96	5.125

DELAY AT TRACKSIDE UNLOADING (MANHR.)

TRAIN	20 FT. CONTAINERS MEAN	20 FT. CONTAINERS ST.DEV.	20 FT. CONTAINERS MAXIMUM	40 FT.CONTAINERS MEAN	40 FT.CONTAINERS ST.DEV.	40 FT.CONTAINERS MAXIMUM
IT6-NTU	.49	.61	1.87	.61	.57	1.92
IT6-OTU	3.13	1.40	5.73	2.43	1.21	4.55
IT4-OTU	1.21	.78	3.32	1.41	1.36	5.63

MEAN TIME IN STORAGE : 1.0886 DAYS

STANDARD DEVIATION : .1957 DAYS

FIGURE 22

OUTBOUND TRAIN STATISTICS

TRAIN NAME	NUMBER OF TRAINS	MEAN DEPT. DELAY	MEAN CONTAINERS LOADED 20'	MEAN CONTAINERS LOADED 40'	CUSTOMER DELAY (MIN.) MEAN 20'	MEAN 40'	STANDARD DEVIATION 20'	STANDARD DEVIATION 40'	MAXIMUM 20'	MAXIMUM 40'	LOAD TIME (HRS.) MEAN	STANDARD DEVIATION	MAXIMUM	MIN. PER CONTAINER
OT-1	1	0.	17.00	29.00	7.0	9.9	9.0	7.8	35.0	29.9	18.00	0.	18.00	23.478
OT-2	1	0.	35.00	19.00	7.8	11.6	8.4	11.6	35.2	40.0	18.00	0.	18.00	20.000
OT-46	1	0.	20.00	42.00	6.3	5.1	7.3	4.9	31.6	19.2	18.00	0.	18.00	17.419

	TIME IN STORAGE BEFORE LOADING (HOURS) AVERAGE 20'	AVERAGE 40'	MAXIMUM 20'	MAXIMUM 40'	TIME AT TRACKSIDE BEFORE LOADING (HOURS) AVERAGE 20'	AVERAGE 40'	MAXIMUM 20'	MAXIMUM 40'
OT-1	15.3	.5	15.3	.5	0.	.1	0.	.1
OT-2	0.	0.	0.	0.	.0	.1	.0	.1
OT-46	.5	.4	.5	.4	.1	.1	.1	.1

FIGURE 23

MACHINE STATISTICS

% TIME SPENT ON EACH ACTIVITY (NOT INCLUDING OFF-DUTY TIME)

MACHINE NAME	STATUS					CONTAINERS HANDLED				
	IDLE	UNLOADING	LOADING	TRAVEL	REPOSITION	DAILY AVG	DAILY MAX	TOTAL	EXTRA MOVES	DISTANCE
FL-A1	55.462	7.330	13.823	22.254	1.132	25	25	25	0	5540.
FL-A1	40.009	12.933	21.375	21.171	4.512	93	93	93	0	0.
FL-A2	40.621	10.283	19.918	26.587	2.591	118	118	118	0	4140.
FL-A3	43.374	10.042	19.348	24.746	2.490	111	111	111	0	8490.
FL-20	61.094	3.197	14.680	20.770	.259	28	28	28	0	0.
FL-E	58.809	14.436	9.929	7.050	9.776	49	49	49	0	0.
8C-P	86.649	3.961	5.320	2.624	1.445	28	28	28	1	340.

FIGURE 24

Figure 25
Daily Status Report

STORAGE AREAS

	NAME	FREE SPACE	CURRENT CONTENTS
1	ES	98	388
2	L1	120	0
3	L2	183	13
4	L3	27	59
5	L4	26	4
6	L5	62	26
7	L6	7	17
8	L7	99	3
9	L8	18	12
10	L9	91	9
11	L10	10	14
12	E2	0	9
13	E3	2	28
14	L11	376	4
15	L12	4	10
16	E4	101	403
17	E1	22	68
18	E6	25	374

TRACKS

NUMBER	LENGTH(IN TEU'S)	FREE SPACE	NO. RESERVATIONS	NO. TO LOAD
TR1	35	35	0	0
TR2	40	40	0	0
TR4	78	78	0	0
TR6	83	83	0	0
TR46	26	26	0	0

OUTBOUND OT-1 HAS 15 CONTAINERS WAITING
OUTBOUND OT-2 HAS 5 CONTAINERS WAITING
OUTBOUND OT-46 HAS 3 CONTAINERS WAITING

4.4.2.2 Machine Activity File

There is also a machine activity file which may be produced at the end of each simulation. Each machine job and the start time of these jobs are indicated, along with the times the machine is out of service (figure 26).

4.4.2.3 Track Allocation

An optional output report is a time/distance plot of the track allocation during a simulation. The graph shows machine working hours and the amount of time required to load or unload each container from its respective train. The time is measured in hours on the x axis while the y axis is divided into track spots (figure 27).

4.4.3 Simulation Log File

4.4.3.1 Description

Most of the Container Terminal Model analysis will be done with output from the graphics postprocessor, another aspect of the CN/TDC project. The simulation model produces a data file containing the plant layout and a log of every event. This data file contains the minimum amount of text so that it can be easily transmitted from the mainframe computer to a microcomputer where it will be processed to produce an animated replay of the simulated operation.

4.4.3.2 Transfer to Graphical Postprocessor

The transfer of the simulation output to the graphical postprocessor is done over telephone lines (see section 5.2).

4.5 Running the Model

For CN users, the procedure to access any part of the Container Terminal Model is as follows:

1) Log on using a valid computer account.

MACHINE MOVEMENTS FOR FL-A2

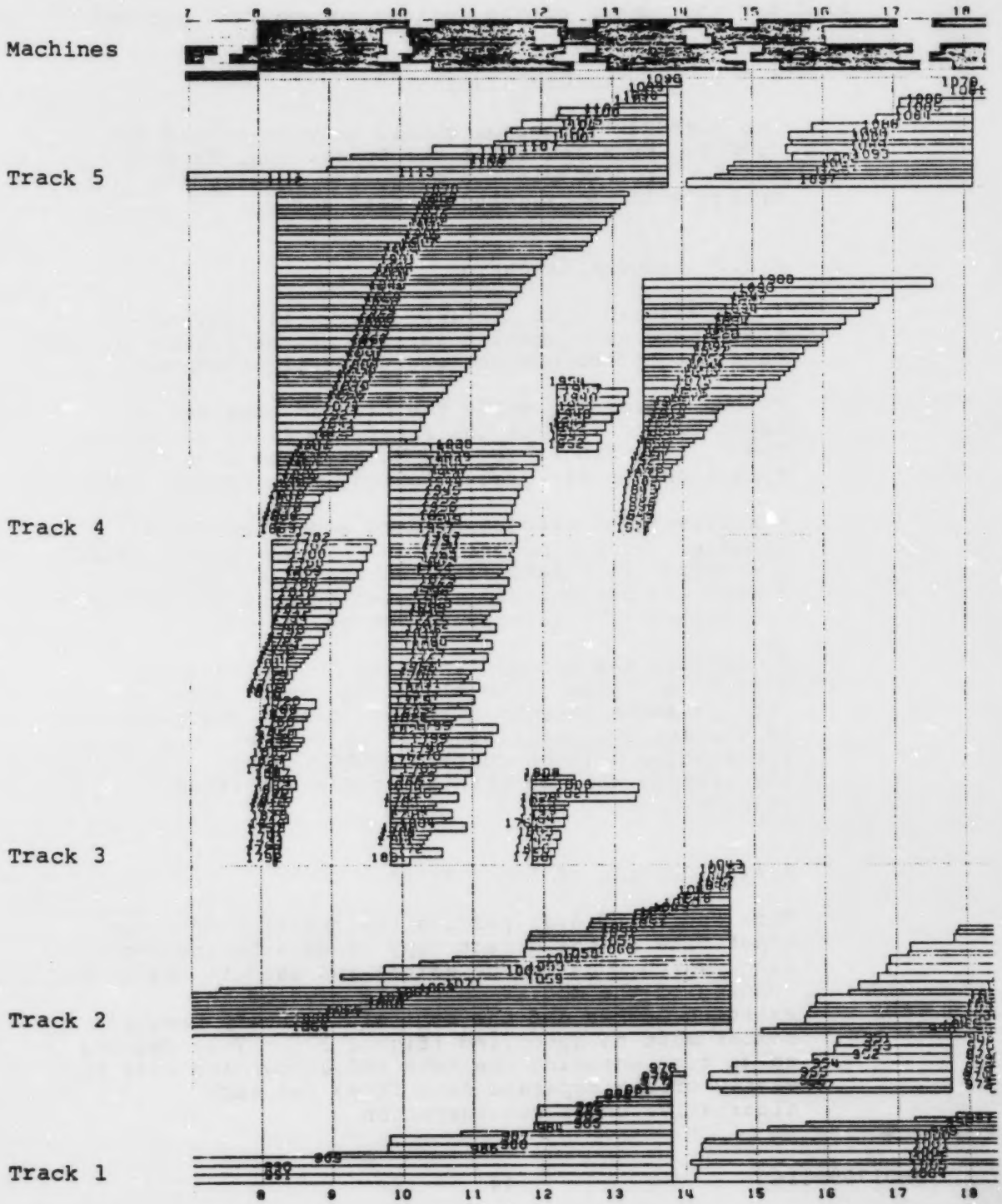
TIME	GATE E5	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10 E2	E3	L11 L12 E4	E1	E6 TR1	TR2	TR4	TR6 TR46
A 11:27:36													TRAVEL					
A 11:32:21																	UNL 3742 67	
A 11:33:18																	TRVL WITH3742	
A 11:37:58													STORED 3742					
A 11:38:43													TRAVEL					
A 11:43:24																	UNL 3702 68	
A 11:44:25																	TRVL WITH3702	
A 11:49: 6													STORED 3702					
A 11:49:51													TRAVEL					
A 11:54:46																	UNL 3693 71	
A 11:55:41																	TRVL WITH3693	
A 11:55:53											STORED 3693							
A 11:56:46											TRAVEL							
A 11:57:11																	UNL 3781 73	
A 11:59: 8																	TRVL WITH3781	
A 11:58:34											STORED 3781							
A 11:59:19											TRAVEL							
A 11:59:54																	UNL 3744 75	
A 12: 0:51																	TRVL WITH3744	
A 12: 1:26											STORED 3744							
A 12: 2:11											TRAVEL							
A 12: 2:55																	UNL 3749 77	
A 12: 3:52																	TRVL WITH3749	
A 12: 4:15											STORED 3749							
A 12: 5:20											TRAVEL							
A 12: 9:15															ST PICKUP 874			
A 12:10:11															LD EMPTY 874			
A 12:11: 3															TRAVEL			
A 12:20: 1	START 44K																	
A 12:33:54	END 44K																	
A 12:39:36	TRAVEL																	

Machine Activity File

FIGURE 26

FIGURE 27

Track Allocation Plot



2) To access any or all of the CTM programs and utilities, select option T.8 in our SPF menu (figure 28). The choices available include program compilation and execution, editing of the data, input file utilities, and a formatted print option.

3) Enter the number of the desired option, and proceed.

4.5.1 Program Compilation

The SIMSCRIPT programs should only be edited and compiled by a member of the Operational Research staff. Upon completion of system development, this option will be disabled on user screens.

4.5.2 Program Execution

It is assumed that the input data file exists and that there is a working version of the program in the computer before program execution is attempted.

To run the model, enter the program name and the input member name in the first two lines of option T.8.2. The simulation may be executed in either foreground or background (batch) mode (figure 29).

For foreground execution, make sure that the line labelled "your name" is blank. If you wish to send the output to a data file, enter 'F' as the foreground option. If you wish to send the output to the screen, the foreground option is 'S'.

To execute the program in batch mode, leave the foreground option line blank. Instead, enter the job card parameters (your name, job class, job priority) in the appropriate lines. If no printer is entered, the listing will be routed to MSGCLASS=T. Otherwise, the listing will be printed at the specified printer.

4.5.3 Copying of Input Files

This option (T.8.3) permits the creation of a new input file by the direct copy of an existing input file, which then may be edited and used in the running of the model. Both the name of the existing member and the name of the newly created member must be specified (figure 30). This feature saves time entering the data and allows the user to easily create separate data files for each alternative under consideration.

4.5.4 Deletion of Input Files

Obsolete or incorrect data files can be deleted from the input dataset (T.8.4). The user may limit the deletion to part of the data file (figure 31).

4.5.5 Editing of Input Files

To create and edit the data file, select option T.8.5. Then enter the file name and file type (old or new), and choose the appropriate section (figure 32). The data file is explained in detail in section 4.2.

Once the file is accessed, data may be typed only in areas with dashed lines. All other parts of the screen are protected. The tab keys may be used to move from one field to the other.

If the value being entered is out of the prescribed range or an alpha character is typed in a numeric field, an error message will be typed in the upper left hand corner. The correction must be made before the user can move to another screen.

Movement to the next screen in the file is accomplished by hitting the PF23 function key. PF22 returns the user to the previous screen.

In sections 2 and 4 of the data file (machine definitions and probability distributions), multiple observations are permitted. Movement from one observation to another is done by hitting either PF19 (backward) or PF20 (forward).

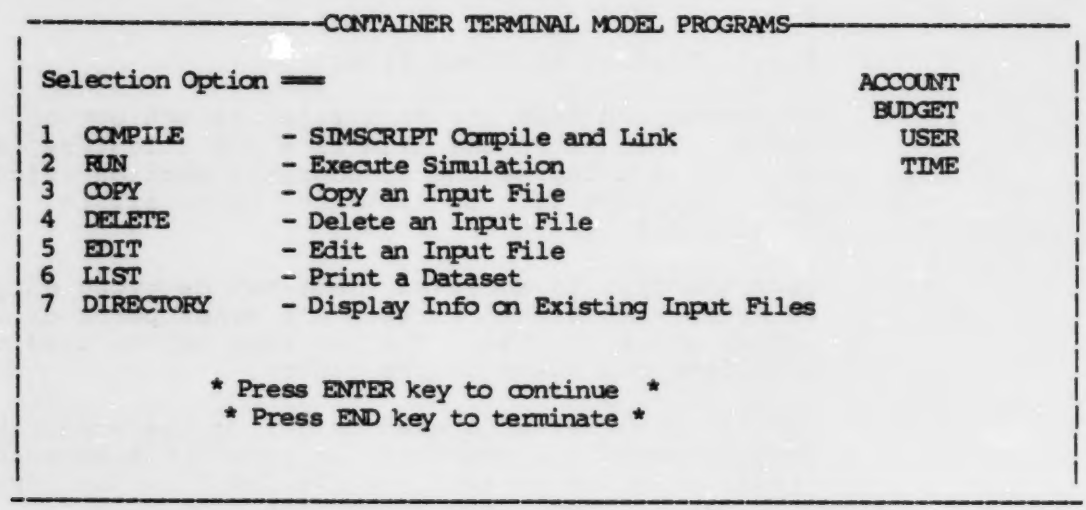
Note that the split screen capability has been disabled in SAS/FSP.

The following is a summary of the SAS/FSP function keys:

PF13 = help	PF14	PF15 = end
PF16	PF17	PF18 = duplicate observation
PF19 = backward	PF20 = forward	PF21 = add new observation
PF22 = left screen	PF23 = right screen	PF24

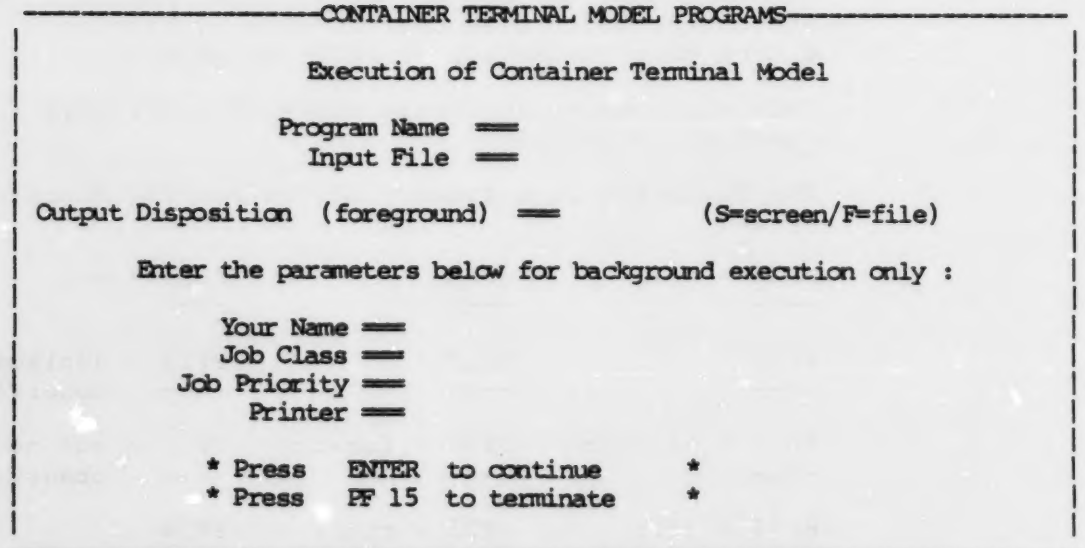
F I G U R E 28

CTM MAIN MENU

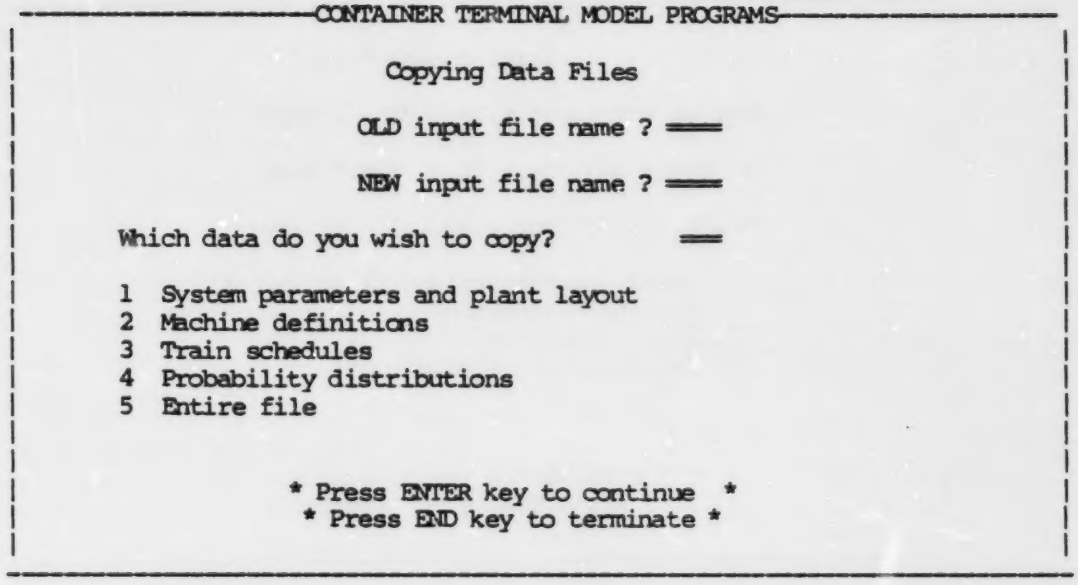

CONTAINER TERMINAL MODEL PROGRAMS
Selection Option ===
ACCOUNT
BUDGET
USER
TIME
1 COMPILE - SIMSCRIPT Compile and Link
2 RUN - Execute Simulation
3 COPY - Copy an Input File
4 DELETE - Delete an Input File
5 EDIT - Edit an Input File
6 LIST - Print a Dataset
7 DIRECTORY - Display Info on Existing Input Files
* Press ENTER key to continue *
* Press END key to terminate *

F I G U R E 29

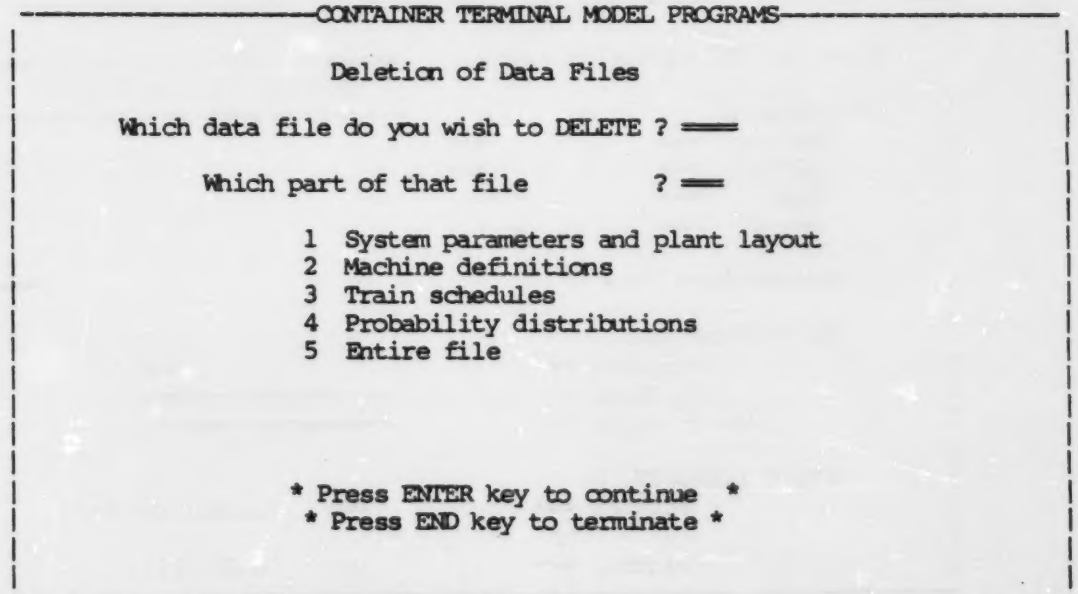
PROGRAM EXECUTION


CONTAINER TERMINAL MODEL PROGRAMS
Execution of Container Terminal Model
Program Name ===
Input File ===
Output Disposition (foreground) === (S=screen/F=file)
Enter the parameters below for background execution only :
Your Name ===
Job Class ===
Job Priority ===
Printer ===
* Press ENTER to continue *
* Press PF 15 to terminate *

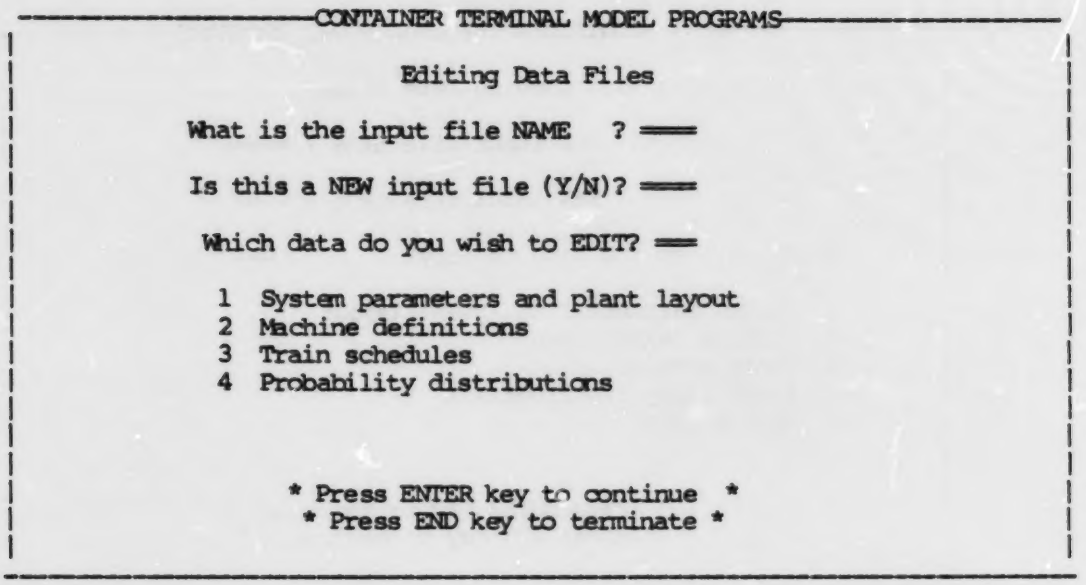
F I G U R E 30


CONTAINER TERMINAL MODEL PROGRAMS
Copying Data Files
OLD input file name ? ===
NEW input file name ? ===
Which data do you wish to copy? ==
1 System parameters and plant layout
2 Machine definitions
3 Train schedules
4 Probability distributions
5 Entire file
* Press ENTER key to continue *
* Press END key to terminate *

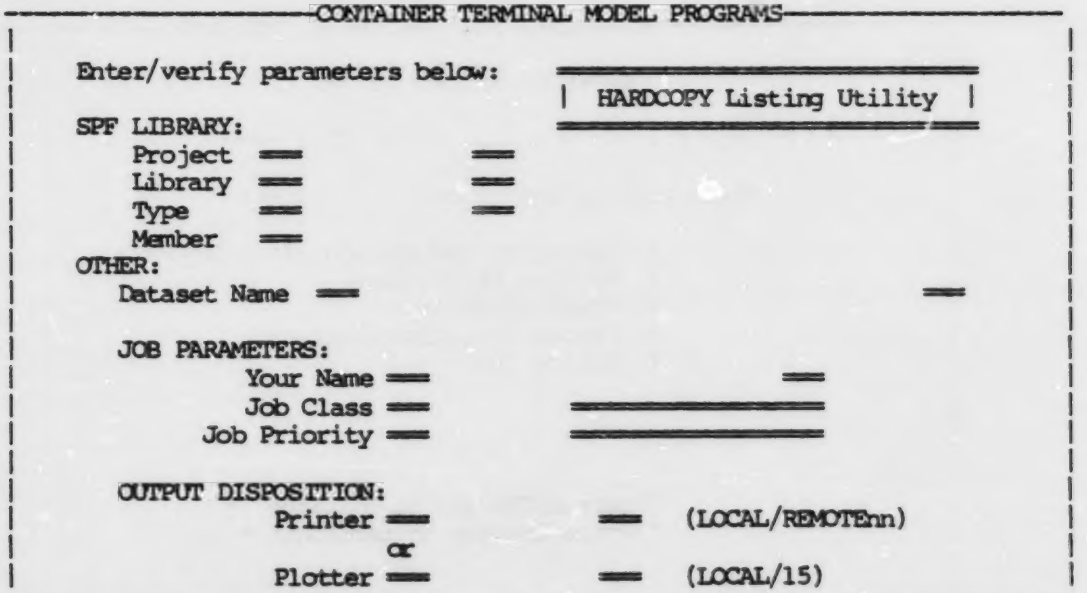
F I G U R E 31


CONTAINER TERMINAL MODEL PROGRAMS
Deletion of Data Files
Which data file do you wish to DELETE ? ===
Which part of that file ? ==
1 System parameters and plant layout
2 Machine definitions
3 Train schedules
4 Probability distributions
5 Entire file
* Press ENTER key to continue *
* Press END key to terminate *

F I G U R E 32


CONTAINER TERMINAL MODEL PROGRAMS
Editing Data Files
What is the input file NAME ? ===
Is this a NEW input file (Y/N)? ===
Which data do you wish to EDIT? ===
1 System parameters and plant layout
2 Machine definitions
3 Train schedules
4 Probability distributions
* Press ENTER key to continue *
* Press END key to terminate *

F I G U R E 33



4.5.6 Printing of Datasets

This utility (T.8.6) prints any permanent or temporary dataset specified, with formatting (figure 33).

4.5.7 Directory of Existing Input Files

This utility (T.8.7) gives a listing of all members in the input data set. Member names are prefaced with a single letter indicating the portion of the input data file they contain:

Y - yard (plant layout and system parameters)
M - machines
T - trains
P - probability distributions.

5. USING THE GRAPHICAL POSTPROCESSOR

5.1 Hardware/Software Requirements

5.1.1 Hardware

The following equipment is used to run the graphical postprocessor:

A) Intel microcomputer - model 330A
B) Raster Technologies Model ONE/20 graphical display controller
C) 11" x 11" digitizer tablet with cursor (mouse) (Figure 34)
D) 13" high resolution colour monitor (CRT). (512 x 512 pixels)
E) Standard terminal

Figure 35 shows how the equipment is connected.

Item (A), the Intel microcomputer, has 320K RAM, a 35 MB Winchester hard disk and 1 MB floppy disk drive. A minimum of two ports are required to run the program, but four ports are preferable. This configuration permits data transfers from a second computer while running the replay.

Item (B), the display controller, converts the signals sent by the computer into graphical images on the colour CRT. The digitizer tablet is used to enter all commands, replacing a keyboard.

A standard terminal is used to boot the program at the start.

5.1.2 Software

All programs on the Intel computer run under the XENIX operating system. The programs that process the event log are written in "C". Instructions for the graphics controller are sent by calling FORTRAN subroutines. These routines were supplied with the graphics controller and are easily called from "C".

With the current version of the operating system, there is a limit of 64K per load module. Therefore, the "C" source programs have been placed in two load modules. The first is used to select the log file and adjust the paths, while the second reads the logfile and displays the events.

FIGURE 34

Digitizing Mouse

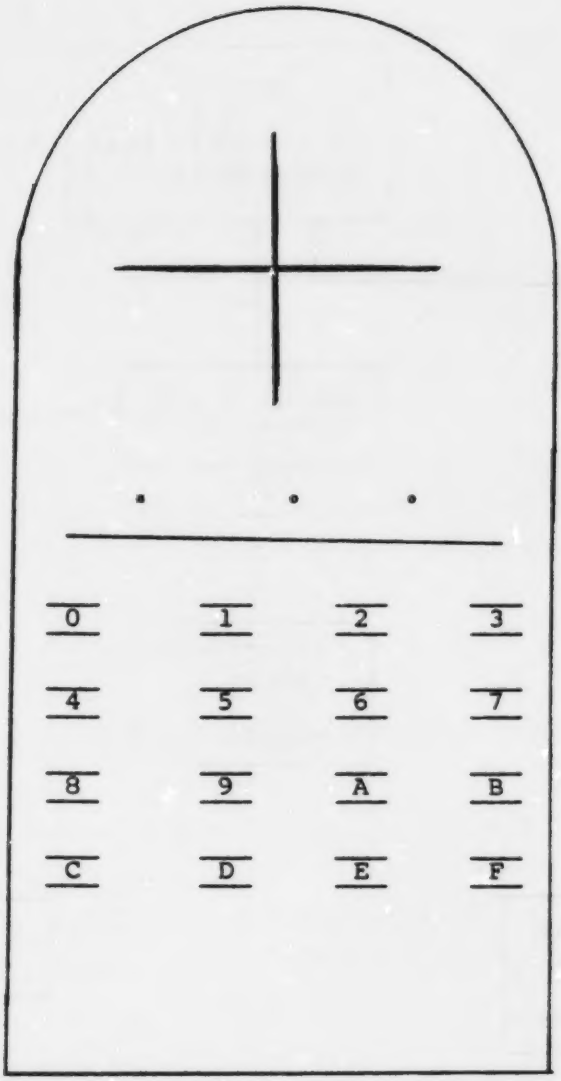
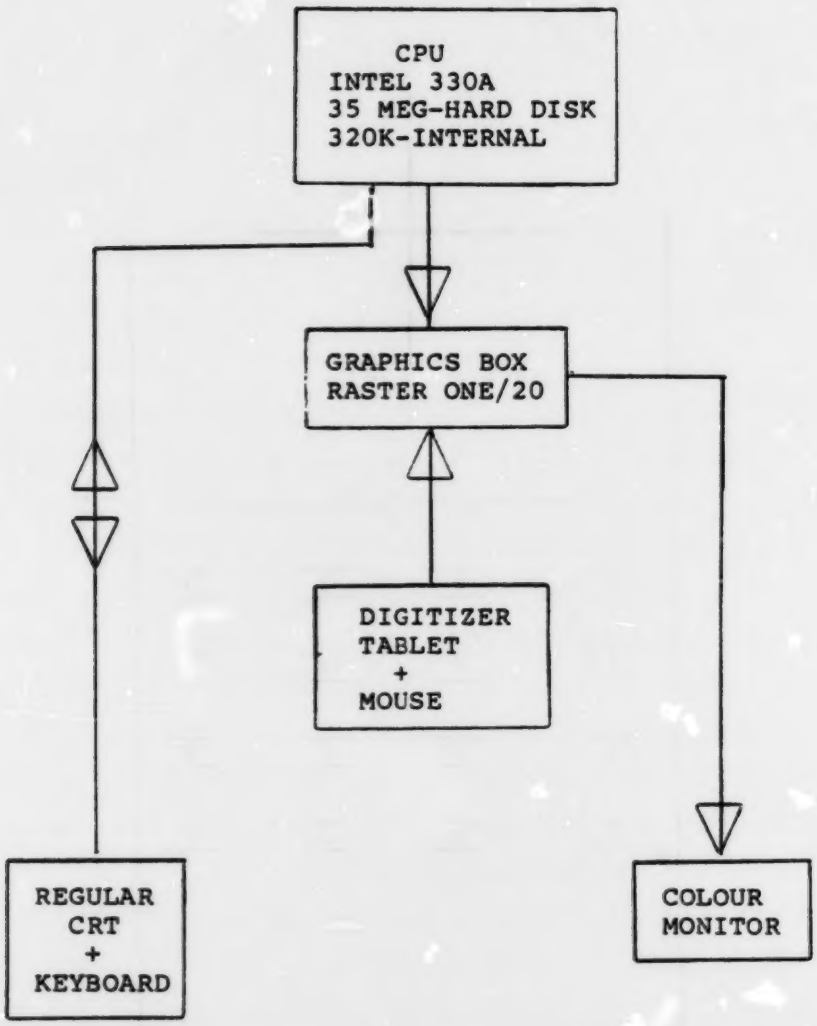


FIGURE 35

EQUIPMENT CONFIGURATION



5.2 Downloading Data

XENIX provides the necessary system routines to connect to an external computer with the "CU" command. By using this it is possible to dial into a second computer and transfer data through an acoustic coupler.

The logfile which is produced by the simulation on another computer is passed down to the Intel in this manner. For one week of simulation, the logfile could contain 15,000 records. It is possible to store several different logfiles on the hard disk at the same time. Each time a file is added to the log file directory "usr/ctm/LOG.data", it will be displayed in the logfile menu shown at start up.

5.3 Set up for Replay

5.3.1 Start System ("Booting")

The first step is to turn on the colour monitor. Next the power supply for the digitizer tablet is plugged in. Finally the display controller is turned on and the reset button at the back pushed twice. At this point the colour screen should be blank, and the graphics programs may be started.

To run the replay programs, it is necessary to access account "CTM" by entering "LOGIN CTM" at the keyboard, followed by a valid password. The prompt "$" will then appear, indicating that the system is ready for input.

The command "cd/usr/ctm/CTM_lib/REPLAY" should be entered in order to move into the directory for running the replay. Typing in "CTMRUN" will cause the program to be loaded into memory and start executing. The start up menu will now appear on the colour CRT and the desired file may be selected.

5.3.2 System Status

A pictorial of a traffic light appears at the bottom of the screen indicating the system status. When the light is red, it is an indication that the system is busy at work and will not receive input from the user. The light turns green when the computer is awaiting input from the analyst.

5.3.3 Selecting the Logfile

After start up, a menu showing all the available logfiles is displayed. A photograph of this menu is shown in figure 36. Up to 6 pages of these files can be shown, with 20 files per page. To proceed to a page above or below, the cursor is moved to either the top or the bottom of the screen. A purple line highlights the file name currently being pointed at. The function of each button on the digitizing mouse is displayed on the screen for easy reference. At this point either button 1 is pressed to adjust the paths (discussed in next section) or button 2 is pressed to begin the replay. In most cases the paths have already been adjusted and the replay option may be selected.

5.3.4 Adjusting the Paths

This option displays the basic yard layout (section 5.4.1). Pressing button 1 causes the current path configuration to be displayed. Paths, shown as green lines, are drawn to represent the routes that loaders and trucks will take when moving between locations. During the actual replay these paths will not be shown.

If paths have never been adjusted before, then a straight line is drawn between the top left corner of each object and all other objects. By pressing button 9 the nearest existing inflection point can be moved. The selected line segment is highlighted in a brighter shade of green, and will follow the position of the cursor. Figure 37 shows a path in bright green that is being adjusted.

When the line segment is in the desired location, button 9 is pressed again to release it. By pressing button "A", a new point may be inserted in a line segment and repositioned. The line segment with the point passing closest to the cursor is selected.

A test can be made to check which line will be selected next: button "8" tests for the nearest old point, while button "B" checks for the nearest new point. With these options the lines are highlighted but remain in their original position. Pressing button F causes a return to the previous menu which allows deletion of any point (button 5), saving the changes (button F), or deletion of all changes (button C).

Figure 37 Path Adjustment

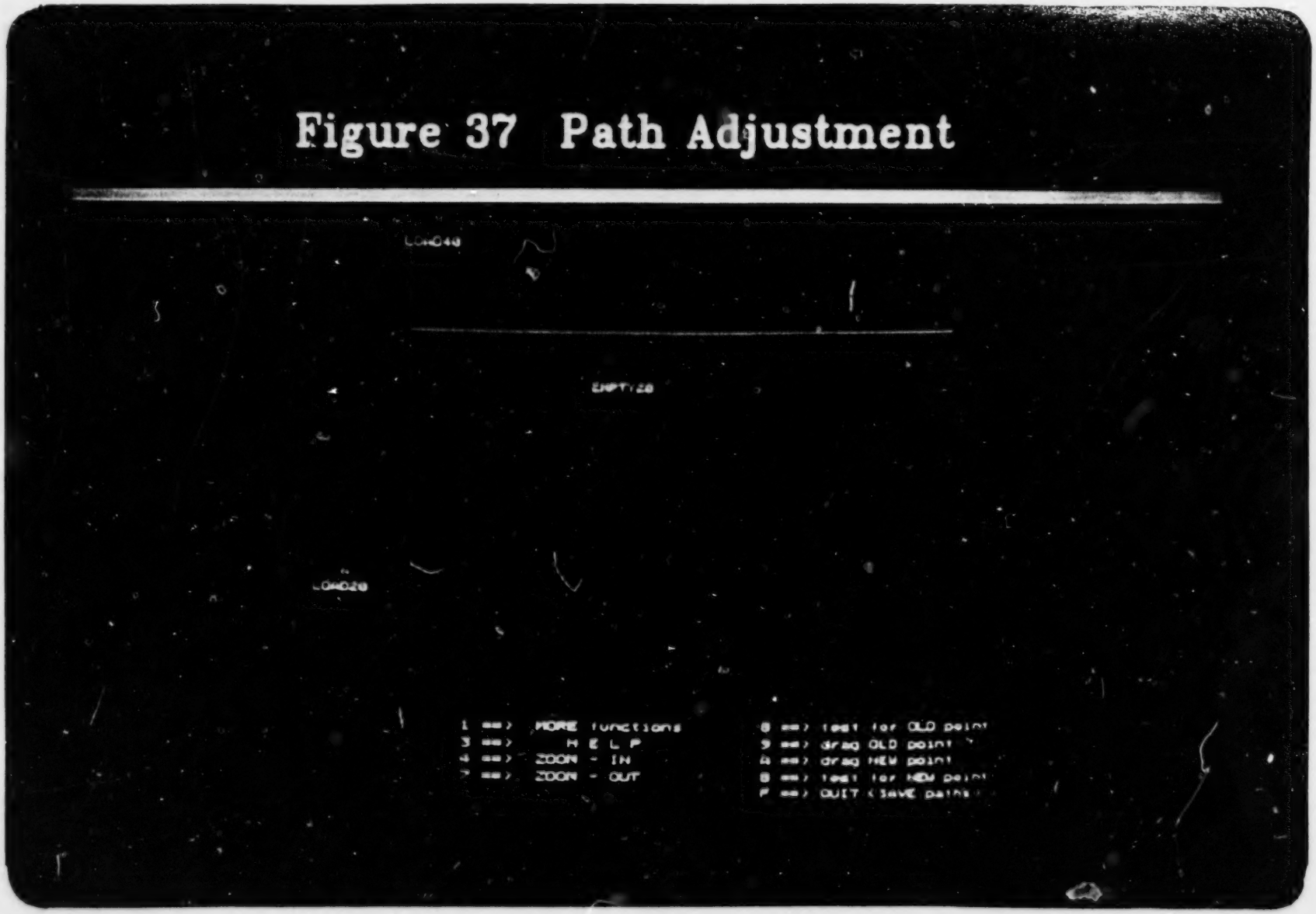
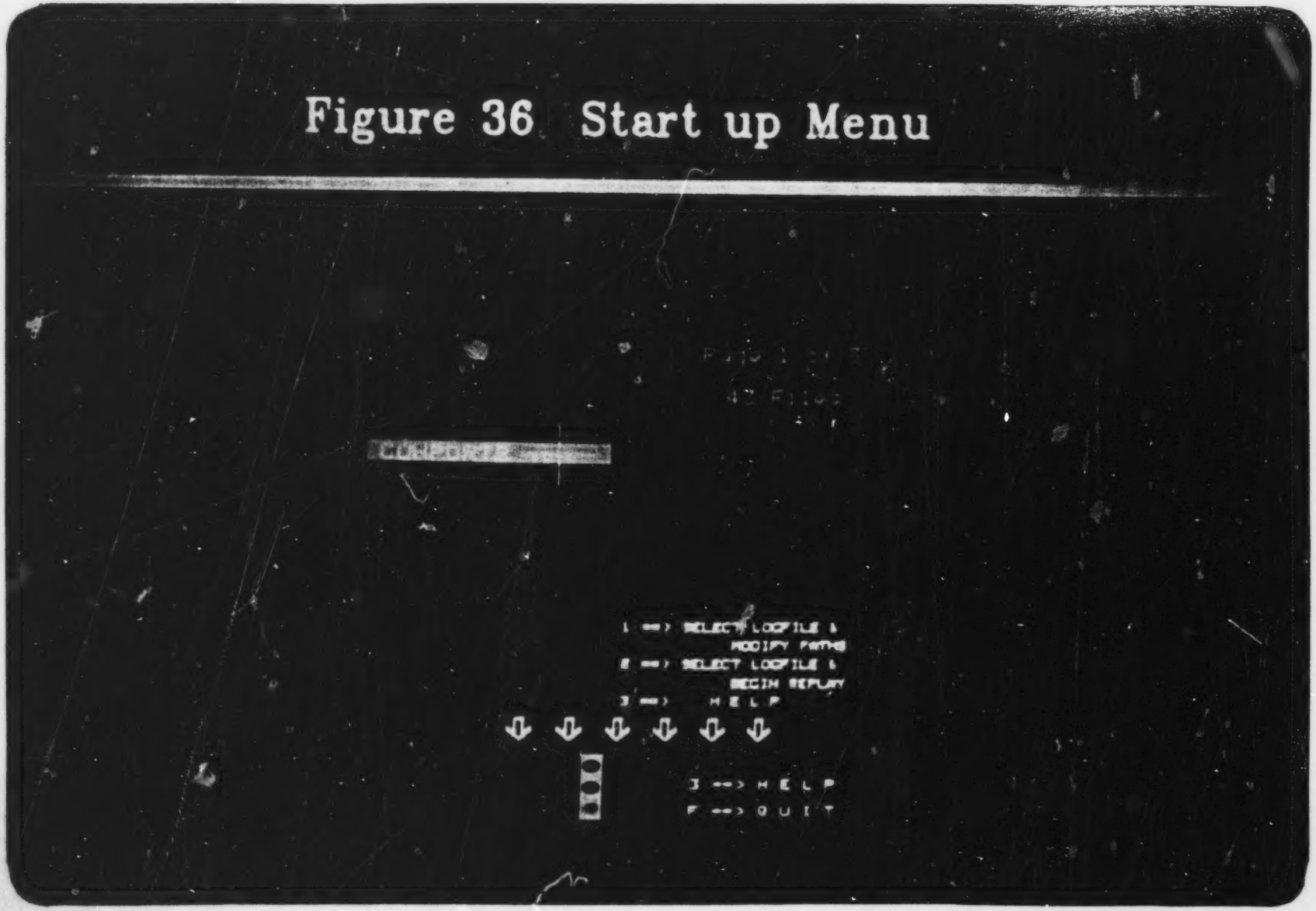

LOAD40
EMPTY:28
LOAD20
1 ==> MORE functions
3 ==> H E L P
4 ==> ZOOM - IN
7 ==> ZOOM - OUT
8 ==> test for OLD point
9 ==> drag OLD point
A ==> drag NEW point
B ==> test for NEW point
F ==> QUIT (SAVE path)

Figure 36 Start up Menu



5.3.5 Setting Speed and Time Limits

Before the replay may begin, it is necessary to set the speed at which events are to be displayed and also the maximum running time. The user is first prompted for the percentage of maximum replay speed desired (a value between 1 and 100). Next, the user enters the time limit in days, hours and minutes. Note that the display at the bottom of the screen updates itself after reading the new settings. Upon reaching the limit during a run, the program will automatically stop and await further instructions. While running it is possible to change any of these values by pressing the button "F" on the cursor.

5.4 Running the Replay

5.4.1 Interpreting the Display

A variety of shapes and colours are used during the replay to represent the yard layout as well as the containers and machines. A flowchart of the logic used in the program to sequence each simulation event is provided in Figure 42. For a complete description of the event records that are transmitted from the simulation to be displayed during the replay, see Appendix 3.

Figures 38 and 39 show two different yards which demonstrate how a replay looks on the screen. The following describes each of the objects drawn on the screen.

5.4.1.1 Storage Areas

A blue rectangle identifies the perimeter of each storage, with the name of the storage appearing in white letters on top. Immediately to the left of the name is a count of the number of containers in overflow storage. A number only appears if the count is greater than zero.

Within the storage, containers are drawn with a space between each row and column. Square shaped containers are 20 feet long, while rectangular containers are 40 feet. Container place of origin is represented by colour, with green for domestic containers and white for all IMPEX containers. This permits the analyst to study the movements of both container types. Each of these colours has three possible shades to

indicate stacking height. The lighter the colour, the more containers that are stacked in a particular spot.

5.4.1.2 Tracks

A horizontal yellow line is used to identify a track. When a cut of containers is placed on a track, the flat cars are indicated by a purple line over the yellow track line. The train name, if any, is shown underneath the first flat car from the left.

Containers themselves are drawn in the same colours as before. The containers are drawn to scale (20 foot or 40 foot). Empty containers are drawn with the bottom half blacked out. If any containers have been spotted beside the track, the total number of such containers is given at the right end of the track.

5.4.1.3 Gate House

All trucks entering and leaving the yard must be processed at the gate house which is drawn as a solid green square with a red roof. Immediately to the right of the gate house is a number indicating the number of trucks awaiting inbound processing. Similarly the number on the left is the number of trucks waiting to leave the yard.

5.4.1.4 Machines and Trucks

Front loaders are drawn as white squares with the number of the loader written inside. Gantry cranes are shown as vertical blue bars over the track and adjacent storage area.

Containers that have been picked up by either type of machine are drawn immediately to the right. As before, green represents domestic while white is for IMPEX. A square shape is used for 20' containers and a rectangle for 40'. Loaded containers are drawn with the centre filled in, while empties have an "empty" centre. When machines are on breaks (coffee, lunch, etc.) the letter "B" is drawn to the right in the spot normally reserved for containers.

Figure 38 Conport Yard

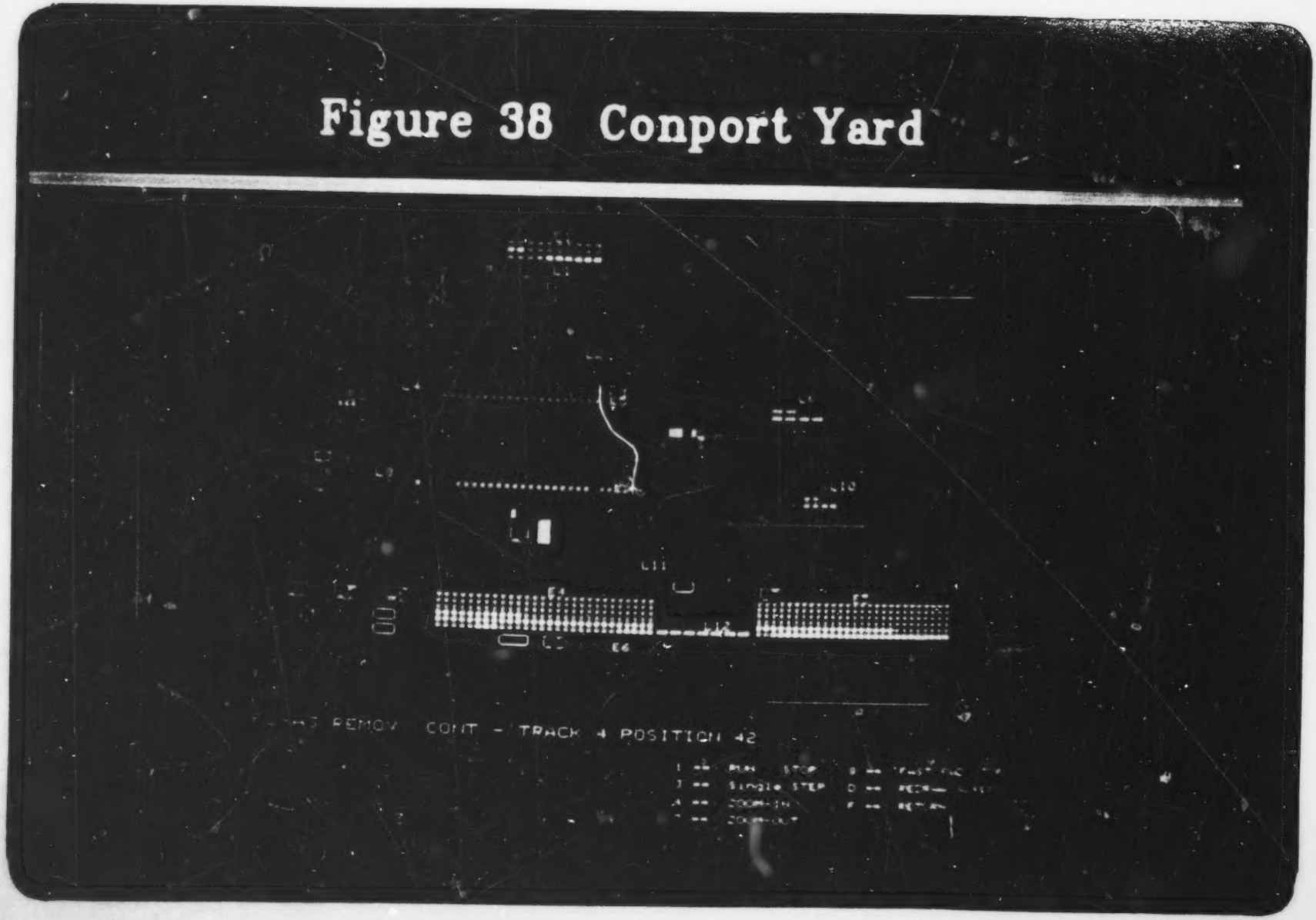
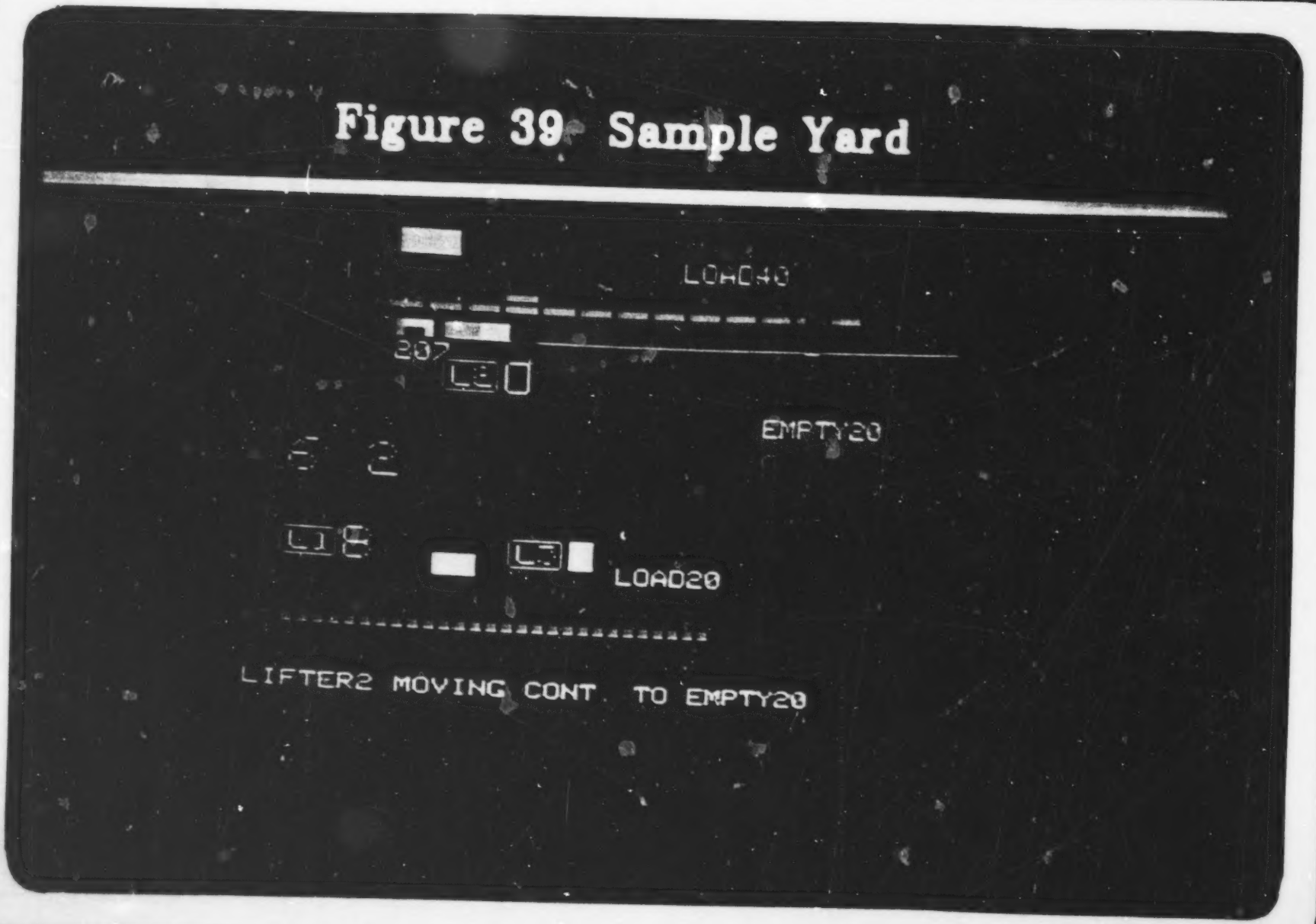


Figure 39 Sample Yard



A truck is represented by a solid red square. If a truck is carrying a container, it is drawn to the right of the square.

5.4.1.5 Container Placement

Front loaders and gantry cranes can pick up or place containers on trucks, flat cars and storage areas. To represent the loader positioning itself and to identify which container it is working on, the container blinks while the operation is in progress.

In general, if a machine is picking up a container, the container blinks for the time required to secure it, after which it is drawn on the machine. Finally the container is erased from the original location.

When a machine is placing a container, the container blinks in the new location while it is being placed, and then is drawn normally. After this the container is erased from the machine.

To provide a better picture of how a container move would appear on the screen, two sequences of photographs have been included. The viewing sequence proceeds clockwise from the top left hand corner of each corner of each page.

The first series (figure 40) is an example of a front loader placing a container on a truck. Frame number 1 is of front loader L1 picking up a container. The selected container is drawn in white and blinks. In the second frame the front loader has completed picking up the container, which is now drawn on the right side of the loader. The empty spot in the storage shows the previous location of the container. If the containers had been stacked two or three high at this spot, the shading would have been adjusted to represent the new stacking height. Frame number 3 shows the front loader placing the container on a truck, represented by a solid red square. The container blinks on the truck while it is being placed. Finally, in frame 4 the container is erased from the front loader and the truck drives to the gate.

The next section describes a crane unloading a flat car (see figure 41).

In frame number 1 the gantry crane (shown as a vertical blue bar) has repositioned itself to line up with the desired container. Frame number 2 shows the crane after it has removed the container from the flat car.

The third frame was taken after the crane was repositioned to place the container in the storage. The spot marked in white, immediately to the right of the crane, is where the container will be placed.

In the final frame the container has been placed and the shading adjusted to indicate that the containers are stacked two high at that spot.

5.4.2 Selecting Single Step/Continuous Mode

There are two methods available for displaying events on the screen, single step and continuous. By pushing button 3 the next event will be displayed. The replay will then wait for another command from the mouse. This is called single step mode. Moving ahead in this manner permits detailed study of a particular operation. Most of the time, however, the continuous mode is used. After pushing button 1 the replay will continue uninterrupted until either button 1 is pushed again or the time limit has been reached. As described previously, the speed can be adjusted at any time during the replay to the user's preference.

As each new event begins, a message appears at the bottom of the screen, indicating what is about to happen.

5.4.3 Fast Forward/Redraw

A very useful feature of the replay is the fast forward command which enables the replay to advance quickly to a particular time. While the replay is displaying events in continuous mode, fast forward may be selected by pressing button 8. Events will

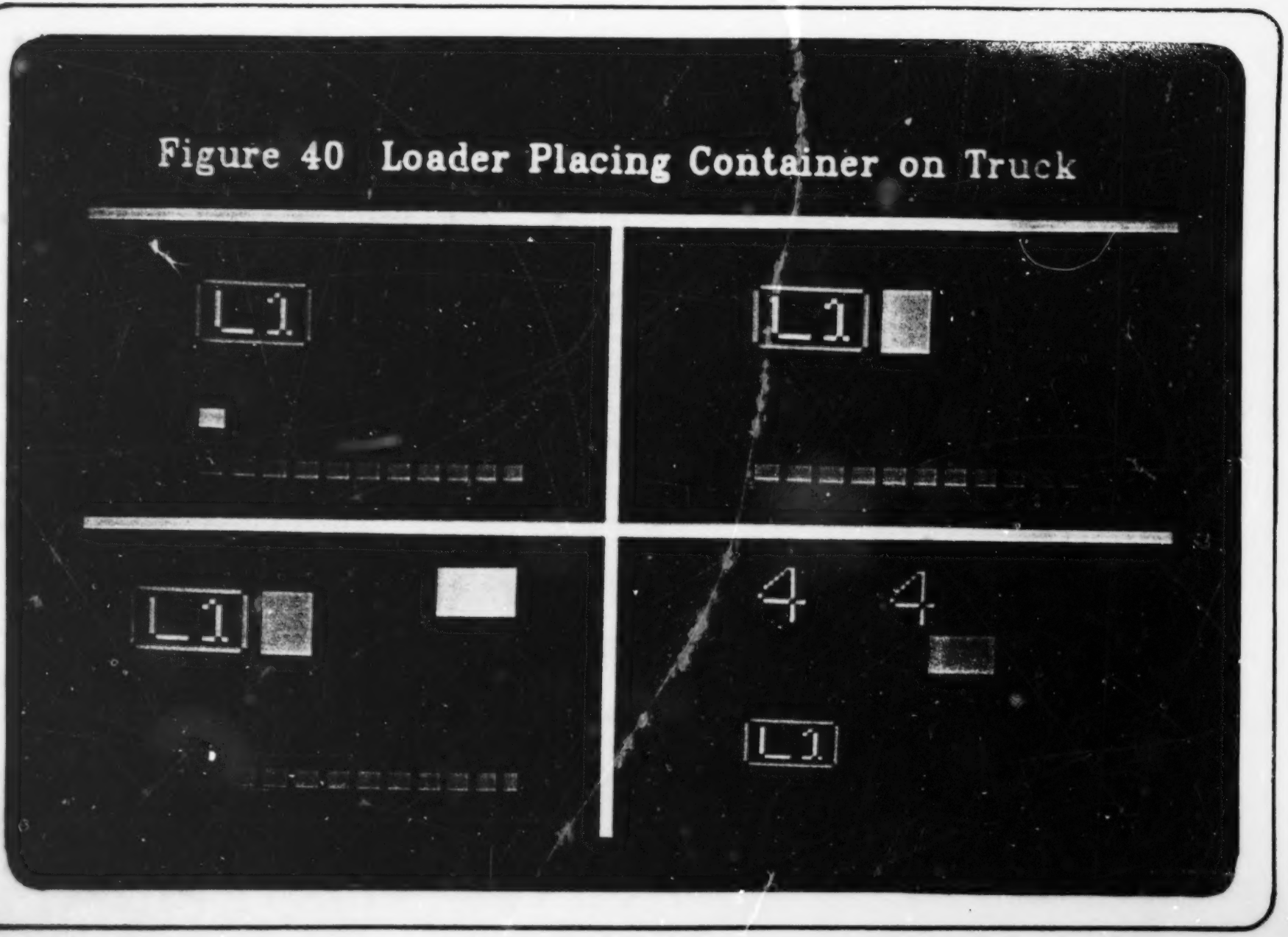


Figure 40 Loader Placing Container on Truck

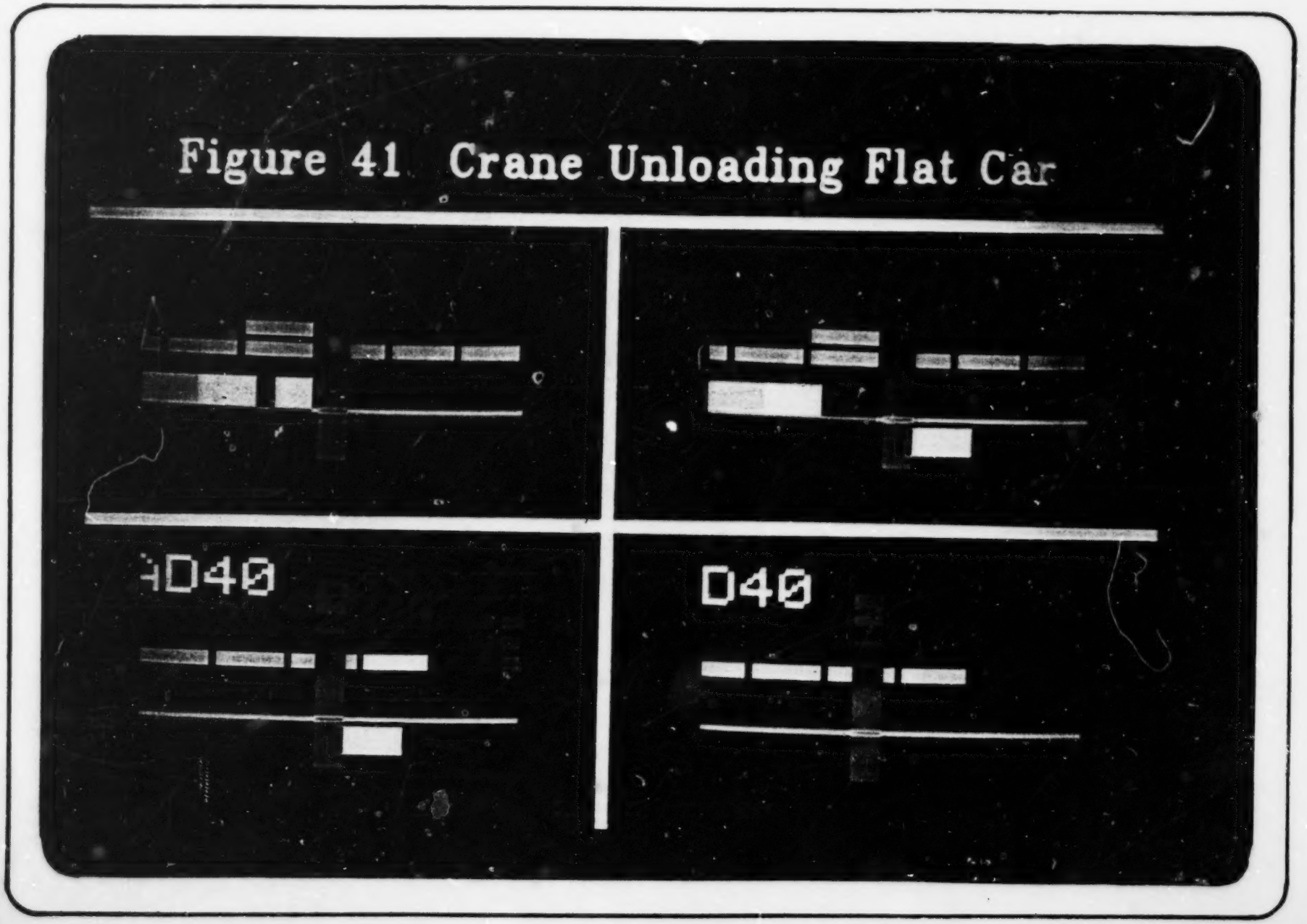


Figure 41 Crane Unloading Flat Car

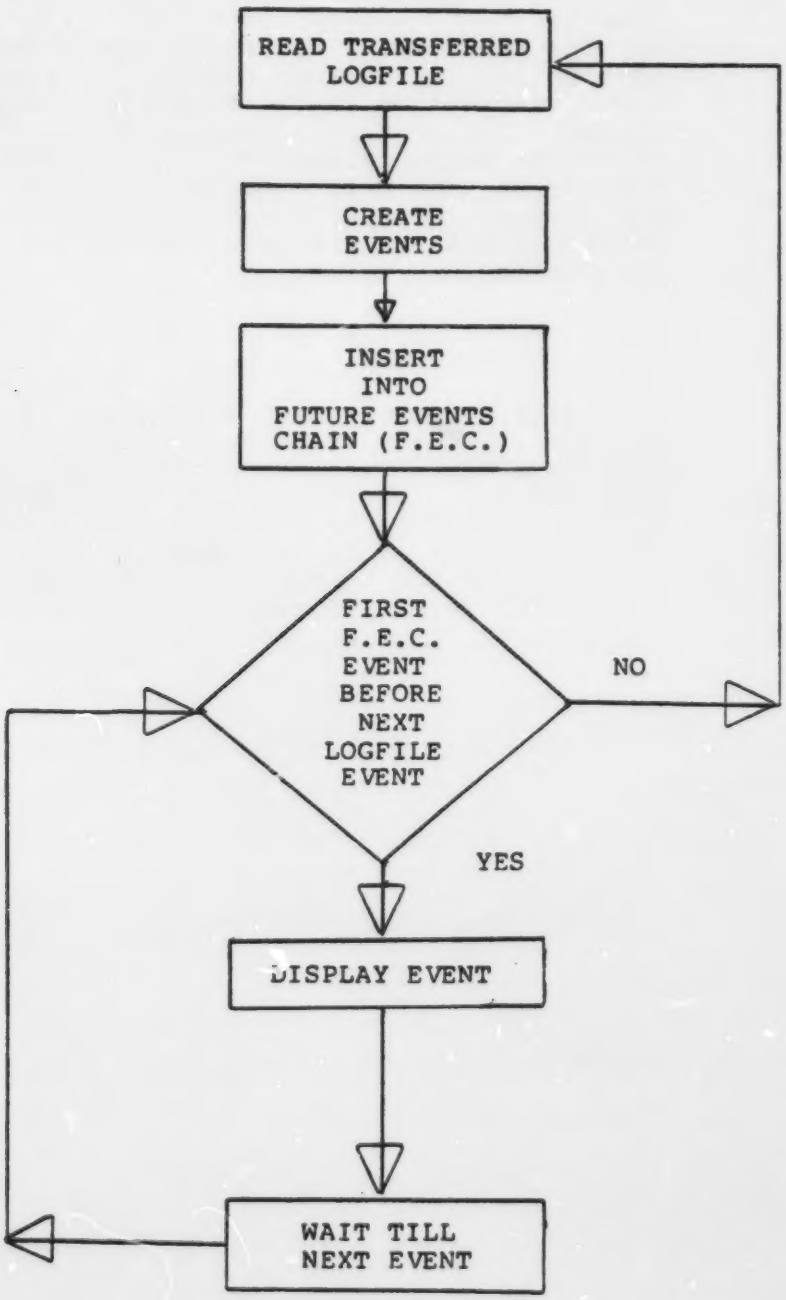
then be processed at approximately 10 times normal speed. While in fast forward, the display will not change but the clock at the bottom of the screen will show the current simulation time. In addition, the location of all containers and front loaders is updated internally. When the desired time has been reached, button 8 is pressed again and the replay will return to normal speed. Alternatively, the fast forward can proceed without user intervention to the time set in the time limit window. The simulation replay should be allowed to run at normal speed for about 30 minutes of simulation time before pressing button D to redraw the screen. This will ensure that the positions of all equipment are properly updated for continuing the display.

5.4.4 Zoom Control

To obtain a better view of the yard it is possible to zoom in on any area, even while the replay is in progress. By moving the cursor over the area to be examined and pressing button 4, the selected area will be magnified by a factor of 2. A magnification of up to 8 is available. While zoomed in it is also possible to pan around the yard and examine different areas. To return to normal magnification, button 7 is pushed.

FIGURE 42

EVENT DISPLAY FLOWCHART



6. FEATURES / LIMITATIONS OF THE CTM

6.1 Features of the Simulation

The model simulates the principal operations of an inland railroad container terminal. Those operations are:
- train arrivals and departures;
- the storage of containers arriving by train or through the gate;
- customer pickup of inbound or empty containers;
- customer arrival with outbound or empty containers;
- the unloading of inbound trains;
- the loading of outbound trains.

The containers being processed in CTM are characterized by their size, place of origin and whether they are loaded or empty. Two types of machines are available to handle the containers: overhead gantry cranes which straddle a track and adjacent trackside storage, and the front loaders which can move anywhere in the yard.

6.1.1 Machine Dispatching

One of the major features of the simulation is its machine dispatching logic. A series of decision rules have been formulated to allow the machine to "intelligently" choose its next assignment. In container terminals, the machines may be assigned to unload an inbound train, but otherwise they search the yard looking for customers to be serviced. In some cases, they are restricted to certain areas in the yard. Since there is no central dispatcher in any of the container terminals under study, the simulation allows each machine to choose its own next job.

The machine searches for a new job at the beginning of each shift, after each work break and after the completion of each job. New jobs (such as the arrival of containers by truck or by train) also trigger the idle machines.

The machine can either work on a single container (job) or be assigned to unload and store a series of containers (task). Highest priority is given to containers which must be placed on outbound trains, and to servicing customers who have arrived to pick

up inbound containers. The servicing of customers picking up and leaving off empty containers is handled next. Lowest priority is given to unloading an inbound train and placing the containers in storage. The criteria for choosing a new job or task for an idle machine is as follows:

```
Does the machine already have a task?
YES - Is there a higher priority job at the same
      location that it can work on?
      YES - interrupts task to handle that
            container (job)
      NO  - Is there a container waiting to be
            unloaded (task list) that has already
            reached its pickup time?
            YES - handles that container
            NO  - continues with next container in
                  task
 NO - Is the machine a front loader?
      YES - Is there a higher priority job at the
            same location that it can be used on?
            YES - handles that job
            NO  - Are there any tasks available?
                  YES - Is there a new task (series
                        of jobs) where the machine
                        can work?
                        YES - creates new task with
                              all the jobs that the
                              machine can work on:
                              begin that task
                        NO  - Are there any tasks
                              assigned to other
                              machines where this
                              machine can be used?
                              YES - create new task
                                    with all the
                                    jobs that the
                                    machine can work
                                    on (up to half);
                                    begin that task
                              NO ...
                  NO - Are there any jobs that the
                       machine can handle for which
                       no better machine can be
                       found?
                       YES - handle that job
                       NO  - IDLE
      NO - Machine is a gantry crane
           Is there a higher priority job at the
           same location that it can be used on?
           YES - handles that job
           NO  - Are there any tasks available?
                 YES - Is there a new task (series
                       of jobs) where the machine
                       can work?
```

YES - creates new task with all the jobs that the machine can work on: begin that task
NO - Are there any tasks assigned to other machines where this machine can be used?
YES - split task by creating new task with all the jobs that the machine can work on; begin that task
NO - ...
NO - Are there any jobs that the crane can handle?
YES - handle that job
NO - IDLE

The following method determines if a given machine is the best machine to handle this job. If this machine is assigned to the location of the job, it is the best machine to use. If there is an available (not travelling or out of service) machine which is already at the container's location and can be used on the container and has either no assigned tasks/jobs or a lower priority task/job, that machine is a better choice than the one that must travel to the location.

In the selection of the job for a gantry crane, it is always assumed that if the crane is available and is able to handle a particular container, it is the best machine for the job.

6.1.2 Storage Assignment

In the CTM, the storage areas separate loaded containers from empty containers, 20' containers from 40' containers, and may distinguish between domestic and IMPEX containers. The assignment of containers to the appropriate storage area can involve a series of decision rules if the terminal being simulated has several areas which handle the same types of containers. In reality, these storage areas may also separate containers by shipping lines. Thus, the assignment algorithm should not place all the containers in one area before starting to fill the other storage areas.

In the CTM, the criteria for choosing the best storage area for a container involves several steps:

Is there a storage area with the same size and type (IMPEX vs. domestic and load vs. empty) attributes as the container and which is less than 75% full?

YES - Select that storage area
If there are several possibilities, choose the storage closest to the container's current location.

NO - Is there a storage area with the same size and type attributes as the container and which has room for the container?

YES - Select that storage area.
If there are several possibilities, check if it is an empty storage.

YES - Choose the area with the most free space

NO - Choose the area closest to the container's current location.

NO - Is there a storage area which handles the same size and contents (load vs. empty) attributes as the container and has enough space for that container?

YES - Select that storage area.
If there are several areas, choose the area closest to the container's current location.

NO - All possible storage areas are full. In this case, choose the closest storage area which handles that size and type of container and place the container in overflow.

When a container is placed in overflow storage, it is not assigned a storage spot. Ordinarily, a container's position in the storage area is defined by its row position, column position and its height in the stacks.

When a request comes for an empty container of a certain size and origin, the container is chosen from the lower left hand corner of the storage area with the same attributes as the container. If there are several areas, the container is selected from the area with the highest percentage of used capacity.

6.2 Limitations of the Simulation

The Container Terminal Model does not include such detail as the tracing of a container's whereabouts after

it leaves the terminal, or the switching required to separate the intermodal flatcars from a larger train.

One of the assumptions in this model is that there will always be sufficient flatcars to handle all the containers arriving and departing by train. Therefore, questions of flatcar allocation and hitch utilization are beyond the scope of this model.

The CTM does not treat containers which are stored on chassis any differently from containers that are stored on the ground. The only railcar to chassis moves occur when the customer has arrived to pick up the container before it has been unloaded from the train.

Several assumptions are made in the CTM which affect the machine movements within the terminal. For example, it is assumed that each storage row is accessible from an aisle, so that it is not necessary to remove containers from obstructing rows before reaching the desired container. Also, machines never check if another machine is on the same path, since it is assumed that there is always room to travel around each other.

The calculations of the distances travelled by the machines are approximate and do not explicitly include the time to travel around obstacles. The algorithm simply calculates the time to travel from the origin's (x, y) coordinates to the destination's in straight lines.

Occasionally, outbound trains include empty containers. In the CTM, these containers are handled in the same fashion as loaded containers, i.e. they arrive at the gate by truck and are loaded on the train. In reality, these containers could also be taken from an empty container storage area.

It is important to keep in mind that only empty containers can be in storage at the start of the simulation. The loaded containers in storage must first arrive by train. Therefore, the empirical distributions of customer pickup time should be taken into account before deciding on a time at which to start collecting statistics. The warm up time must be long enough to sufficiently fill loaded container storage and have customer pickups already in progress.

The Container Terminal simulation was designed specifically for inland container terminals which handle standard containers. If the CTM is to be used to study other facilities such as port terminals, combined piggyback/container terminals or those handling container lengths other than 20' or 40', modifications would have to be made to the existing preprocessor and SIMSCRIPT program.

6.3 Features of the Postprocessor

The postprocessor uses state of the art technology to quickly display the alternative designs and operating strategies simulated by the CTM.

It is designed to supplement the standard output produced by a simulation. For statistics such as machine utilization and yard throughput, it is still necessary to use the simulation reports. For many studies, however, which involve tracing the moves of each machine, it can be a very tedious process if only simulation printouts are available. The postprocessor is well suited to providing information on the tasks each machine performs, the amount of movement required and the overall efficiency that the yard is operating at. Anyone familiar with yard operations can readily understand what occured during the simulation. This is useful in proving the validity of the simulation, particularly to the personnel who must work with the final yard design. If, for example, the yard becomes congested, the problem areas become immediately obvious on the screen. As containers begin to overflow storage areas, indicators on top of each storage will light up, showing the number of excess containers. Queue lengths of trucks arriving and departing from the gate are also constantly updated, quickly indicating if unacceptable delays are occuring.

Running the replay is relatively simple, since all commands are entered through a mouse, (see Figure 34) rather than a standard keyboard. The purpose of each button is written on the screen for quick reference. This enables anyone to begin using the replay on their own in a short period of time.

A final feature of the postprocessor is that it can be modified with minimum effort to replay other types of similar simulations. This would include models where a limited number of objects are moving between locations on fixed paths.

6.4 Limitations of the Postprocessor

6.4.1 Yard Display

Due to the limited space on the colour screen, the postprocessor is only able to display a stylized version of a container yard. In addition, tracks have to be drawn on the horizontal axis. After the program reads in the co-ordinates of the gate, tracks and storages, the scale on the x and y axis is adjusted to fit the available space on the screen.

Container size in each storage is a function of the number of rows and columns in the storage, and the storage dimensions. The postprocessor first calculates how many pixels can be used to draw each container and then rounds down to the nearest integer. This rounding down may cause blank places to be left along the edges of some storages. The best solution to this problem is to change the dimensions of the storage slightly.

6.4.2 Memory Capacity

The version of the "C" compiler which was used to write the programs supports a load module size of 64K and another 64K for variable allocations. This small size has limited the features that could be placed in the postprocessor and the size of yard it can handle. This has not proved to be a serious problem, however, as all the important features are now in the program. For example, it is able to run with data from Conport, CN's largest container terminal. At a later date, the programs can be transferred to a larger system supporting "C" and developed further.

There is no precise limit on the number of tracks and storages that may be created. Any number of loaders and cranes may be created, but a maximum of 75 trucks can be in the yard at the same time.

6.4.3 Speed

The speed of the replay depends upon the microcomputer being used and the type of interface between the CPU and the graphics controller. The adjustable speed factor given at the bottom of the screen is only a relative number, reflecting the percentage of the computer capacity being used. The numbers quoted below are for an Intel 330A microcomputer with an 8086 chip and a serial interface to a Raster Technologies model ONE/20 display controller.

For a light day in a small yard, the ratio of simulation to real time is about 20 to 1 (i.e. 20 hours of simulation replay shown in 1 hr. real time). For a busy day in a large yard, the ratio may be down to 10 to 1.

7. MODEL VERIFICATION, VALIDATION AND APPLICATIONS

7.1 Model Verification

Verification of a simulation model involves testing the individual components of the model to ensure that each part works as we assume it does. This contrasts with model validation, which tests the entire model to see if its results resemble the real world system.

The CTM program was extensively tested using sample data sets and different random number generators. The data sets were set up to focus individually on the different model components (e.g. train loading and unloading, empty container handling). These tests allowed errors in the program and in the model logic to be traced and corrected. Various enhancements were made to the model as a result of the verification.

The graphical postprocessor proved to be a valuable tool in model verification, especially on illustrating event sequencing problems. The postprocessor was only used on a limited basis since it was being developed at the same time as the simulation, but indications are that it will prove very useful in subsequent studies.

7.2 Validation

The purpose of validation is to ensure that the simulation model behaves in a similar manner to a real yard. The container terminal selected for the test was Conport, in Toronto. It was chosen for two reasons: firstly, if the simulation could adequately represent a large complex operation, it would undoubtedly be able to handle smaller yards as well; secondly, it was proposed to use Conport as a test application, and the validation run was seen as forming the base case for that project.

In order to describe and measure actual operations at Conport, three sources of data were used. In chronological sequence these are:

(a) Yard cards for August and September, 1983. These punched computer cards were used up to January 1, 1984 to control the inventory of containers in the yard and to provide a record of containers passing through the yard. For each container arrival at the yard, a card is produced which includes such data as: arrival and departure times, load or empty condition, origin and destination stations, and size of container.

(b) Sample week of December 5-9, 1983. A team of Industrial Engineering personnel visited Conport and collected data on operations during that week. Included were traffic levels in and out on trains and at the gate, yard inventory levels, hand cards showing detailed lift machine tasks and shifts, machine downtime records, yard layout, gate operations, track assignments and other operational details.

(c) Time studies. During March and April of 1984 time studies were conducted on lift machine operations, and on truck movements and waiting times within the yard.

The following table lists the computer simulation input data items, and indicates for each which of the above three data sources was used.

Table 1 Sources of Simulation Input Data

	(a)	(b)	(c)
Track definition		*	
Gate definition		*	*
Storage area definition and boundaries		*	
Machine shift definition		*	
Machine activity times			*
Machine assignments		*	
Outbound/Inbound train definition		*	
Inbound train distribution - customer arrival times	*		
Daily customer arrival distribution	*		
Outbound train distribution - container arrival times	*		
Empty container distribution	*	*	

The computer simulation was run with traffic levels and yard resources closely matching actual levels of the sample week. Output measures from the computer run were compared to expected results based on the input data. The following table summarizes the comparisons.

Table 2 Validation Results

Statistic Measured	Simulation Results Compared to Expected Results
Customer delay at gate	-3%
Gate traffic level	+1%
Containers arriving by train	+1%
Containers departing by train	-1%
Contents of loaded container storage	-2%
Contents of empty container storage	+3%
Loading machine utilization	+1%
Machine average movement distance	+4%

One other important measurement is customer delay in the yard waiting for service by a lifting machine. Some measurements of customer delay were made after the sample week. Because traffic levels and number of machines in service were different from the sample week the results are not directly comparable. An adjustment was made to the observations to enable them to be used to make a rough comparison between actual and simulated customer delay. We feel that the simulation results are within 3 minutes of the probable actual average delay during the sample week.

Taken as a whole, the simulation's results are very close to those expected. We conclude that the simulation model adequately represents the operations of a real container terminal.

7.3 Applications

In order to test the Container Terminal model as it will be used, a trial application was performed. Its objective was to determine how many additional operating lift machines would be required to handle a 25% increase in traffic levels. Customer delay must be no greater than that for the base level of traffic and lift machines.

The base run for the application was the validation run. All traffic levels were increased by 25%. Three runs were done with different numbers of lift machines: first, with the number unchanged from the base run; second, with one additional machine operating for three shifts; and finally, with a second additional machine operating only for the day shift (0800 to 1600 hours).

Although we were not studying gate resources, the number of servers there was increased for most of the day. This was done to prevent a large queue build-up which would affect the rate of container entry into the yard.

The following table shows the levels of resources for the base run, and for the three application runs:

Table 3 Level of Yard Resources in Trials

GATE

Time of Day	Base Run	Application Runs	% Increase
00:00 to 06:00	1	1	0
06:00 to 07:00	1	2	100%
07:00 to 08:00	2	2	0
08:00 to 12:00	2	3	50%
12:00 to 13:00	2	4	100%
13:00 to 16:00	3	4	33%
16:00 to 18:00	2	3	50%
18:00 to 20:00	2	2	0
20:00 to 24:00	1	1	0

LIFTING MACHINES

Time of Day	Base Run & Run # 1	Run # 2	Run # 3
00:00 to 08:00	3	4 (+33%)	4 (+33%)
08:00 to 16:00	6	7 (+17%)	8 (+33%)
16:00 to 24:00	4	5 (+25%)	5 (+25%)

The following table shows some comparative measures from the simulation runs. In each case, the comparison is made to the base run (the run used to validate the model). The measures selected are those which are affected by the number of loading machines in operation.

Table 4 Comparisons to Base Case

Statistic Measured	Run # 1	Run # 2	Run # 3
Average Customer Delay	+69%	+23%	-31%
Containers Unloaded	+25%	+25%	+25%
Containers Loaded	+18%	+22%	+25%
Machine Utilization	+17%	0%	-3%
Machine Travel Distance per Container	-10%	0%	+2%

It is obvious that the 25% traffic increase in Run # 1 degraded customer service, and affected the loading of outbound containers. There was insufficient loading machine capability at peak demand periods to complete the loading before pull time. As a result, the number of outbound containers actually loaded has increased by only 18% whereas the number available to be loaded increased by 25%. The number of containers handled by loading machines did increase by 25%, as those not put onto trains were unloaded from tracks and put into temporary storage. Machine utilization did not increase by 25% but only by 17% because the average distance the lift machines had to travel per container handled decreased by 10%. The increased workload meant that tasks tended to be closer together.

Run # 2 had the same traffic level as Run # 1, but had one additional lifting machine operation during all three shifts. The extra capacity has improved customer service, and allowed more containers to be loaded onto outbound trains. Performance was not as good as the base case, as customer delay was still 23% worse, and the increase in outbound loadings was not yet up to the desired 25% increase.

For the third run, one more lifting machine was added, but just for the peak shift from 08:00 to 16:00 hours. Now customer service has improved; delays being 31% lower than the base case. All outbound containers were able to be loaded. Machine utilization was lower than the base case as more capacity was added than was necessary to complete all the work available.

This simplified example shows how the model can be used to study a real terminal. Other application studies would include other resources in addition to lifting machine capacity, such as storage capacity, trackage and gate activities.

8. CONCLUSIONS

The Container Terminal Model (CTM) comprises a computer simulation model and post-simulation graphical output package. Together they form a very powerful system for analyzing the effect of alternative equipment, layout and operating procedures at an inland container terminal. The postprocessor adds an extra dimension to standard simulation output by dynamically showing the movements within a terminal.

Testing and validation of the CTM was carried out using data from CN's Conport terminal in Toronto. Current traffic levels, projected traffic increases and the effects of additional machines in alleviating yard congestion were examined. The results of these analyses are being used in CN's present study of Conport yard.

The graphical postprocessor is a prototype developed as a compromise between traditional simulation methods and fully interactive graphical simulation. The postprocessor serves three purposes.

First, it is very effective as a means of presenting results by showing the simulation behavior. Management and operations personnel can easily understand the steps the simulation goes through to generate results, increasing their confidence in the model.

Secondly, the postprocessor is a valuable tool in debugging the model. It is particularly useful in studying event sequencing, which must be done in program verification and validation.

Finally, the postprocessor can be used to analyze the simulated terminal performance. Specific time frames in a simulation can be played back so that the analyst can see and understand the operation. The playback permits detailed analysis of periods where peak traffic, congestion, high delay, etc. may have occurred. Typically these are important situations that need to be well understood for proper design. The postprocessor has received a very favourable reaction at CN.

A P P E N D I X 1

Technical Terms

Boot - load program into memory of computer.

CPU - central processing unit.

CRT - cathode ray tube.

Computer port - an outlet on the computer through which information is sent and received. Normally, a computer terminal is connected to a port.

Domestic container - container which originates and terminates in Canada.
e.g. CN TerraTransport containers (to and from Newfoundland)

IMPEX container - contraction of import/export; container which travels to and from Canada by ship.

MB - megabytes = 1 million bytes

Mouse - device for positioning cursor on screen and entering commands.

Pixel - the smallest sized area on a CRT that can be individually drawn.

RAM - random access memory.

Spotting - action of placing a container beside the track before loading it on the flatcar.

TEU - twenty-foot equivalent unit; a measure of container capacity.
e.g. 1 TEU = 1 20 ft. container

Winchester - a hard disk with a large storage capacity and high speed retrieval capability.

APPENDIX 2

Description of Input Variables

The input variables are entered via a SAS/FSP input screen, processed by a SAS program (which also adds some variables to the data set), and finally read into the SIMSCRIPT program.

The following list specifies the variable name in the SIMSCRIPT program. The variable type is either T for text, I for integer, or R for real. The line numbers (e.g. .....1) indicate the start of a input line in the data set being read into the CTM. DO loops are also indicated. Any variables that are generated by the SAS program are noted by an asterisk (*).

SIMSCRIPT NAME	VARIABLE TYPE	UNITS
..... 1		
run_id	T	
duration	I	days
stats_start_time	I	hour of day
stream	I	1 - 9
* no_of_traces	I	1 - 3
* n. track	I	1 - 9
car_size	R	feet
truck_speed	R	m.p.h.
switch_time	R	min.
..... 2		
* n.storage	I	
..... 3		
(for 1 to no_of_traces)		
start_time	R	hour of day
length	R	hours duration
value	T	
..... 4		
* num_gate_shifts	I	1 - 5
..... 5		
(for 1 to num_gate_shifts)		
gte_shift_hour	R	hour of day
gte_servers	I	

SIMSCRIPT NAME	VARIABLE TYPE	UNITS
..... 6		
gte_processing_time	R	minutes
gte_std_dev	R	minutes
lc_firstx..	I	feet
lc_firsty..	I	feet
..... 7		
(for 1 to n.storage)		
str_name	T	
str_initcap	I	TEU's
str_sizecon	I	20/40
str_loadcon	T	L/E
str_origcon	T	D/I
str_levels	I	
str_rows	I	TEU's
str_columns	I	
str_row_direction	T	H/V
lc_firstx..	I	feet
lc_firsty..	I	feet
lc_secondx..	I	feet
lc_secondy..	I	feet
..... 8		
(for 1 to n.track)		
trk_number	T	
lc_firstx..	I	feet
lc_firsty..	I	feet
lc_secondx..	I	feet
lc_secondy..	I	feet
..... 9		
* n.machine	I	
..... 10		
(for 1 to n.machine		
mac_name	T	
mac_type	T	C/L
mac_speed	R	mph
mac_strt_shift	R	hour of day
mac_end_shift	R	hour of day
mac_break_schedule	I	
mac_sdev_breaks	R	hours duration
mac_length_breaks	R	hours duration
days	T	1-7
mac_assigned_con_type	T	E/L/A
mac_assigned_con_size	T	20/40

SIMSCRIPT NAME	VARIABLE TYPE	UNITS
mac_ld_truck_time	R	minutes
mac_unl_truck_time	R	minutes
mac_ld_train_time	R	minutes
mac_unl_train_time	R	minutes
mac_pick_storage_time	R	
mac_place_storage_time	R	
* num_loc		
(for 1 to n.machine	T	location i.d.
loc_value		
..... 11		
* n.intrain	I	
* n.outrain	I	
..... 12		
(for 1 to n.intrain)		
it_name	T	
it_mean_cont	R	
it_sdev_cont	R	
it_pref_track	T	
it_delay_time	I	hours duration
it_hr_arrival	R	hours of day
it_dist_no	I	
days	T	1-7
..... 13		
(for 1 to n.outrain)		
ot_name	T	
ot_mean_cont	R	
ot_sdev_cont	R	
ob_tracks	T	
ot_trkside_time	R	hours duration
ot_hr_pull	R	hour of day
ot_cut_off	R	hours duration
days	T	1-7
* ot_num_of_blocks	I	
(for 1 to ot_num_of_blocks		
ob_distn	I	

SIMSCRIPT NAME	VARIABLE TYPE	UNITS
..... 14		
* n.in_distribution	I	
* n.daily_in_distribution	I	
(for 1 to n.in_distribution		
..... 15		
* num_of_elements	I	
..... 16		
(for 1 to num_of_elements)		
el_hour	R	
el_frac	R	0-1
..... 17		
id_daily_dist_no	I	
id_imp_pc	R	0-100
id_20_imp	R	0-100
id_ld_imp	R	0-100
..... 18		
id_20_dam	R	0-100
id_ld_dam	R	0-100
(for 1 to n.daily_in_distribution)		
..... 19		
* num_of_elements	I	
..... 20		
(for i to num_of_elements)		
el_hour	R	
el_frac	R	0-1
..... 21		
* n.out_distribution	I	
(for 1 to n.out_distribution		
..... 22		
* no_of_elements	I	

SIMSCRIPT NAME	VARIABLE TYPE	UNITS
..... 23		
(for 1 to no_of_elements		
el_hour	R	
el_frac	R	0-1
..... 24		
od-percent	R	0-100
od_imp_pc	R	0-100
od_20_imp	R	0-100
od_ld_imp	R	0-100
..... 25		
od_20_dam	R	0-100
od_ld_dam	R	0-100
..... 26		
* n.mt_distribution	I	
(for 1 to n.mt_distribution		
..... 27		
* no_of_elements	I	
..... 28		
(for 1 to no_elements		
ee_hour	R	1-24
ee_arrivals	I	
ee_departures	I	
..... 29		
days	T	1-7
em_20_pc	R	0-100
em_imp_pc	R	0-100

APPENDIX 3

Description of Event Records

TRAIN EVENTS

EVENT DESCRIPTION	EVENT NO.	PARAMETERS
TRAIN ARRIVAL WITH CONTAINERS	001	TRAIN NO., TRACK NO., NO. OF CONTAINERS, START POSITION
FLAT CAR RECORD	—	CAR NO., LOAD, ORIGIN, LENGTH
TRAIN DEPARTURE WITH CONTAINERS	002	TRAIN NO., TRACK NO., POSITION 1ST. CONTAINER, POSITION LAST CONTAINER
BLANK OUT TRAIN I.D.	003	TRAIN NO., TRACK NO., POSITION 1ST. CONTAINER, POSITION LAST CONTAINER
WRITE TRAIN I.D. UNDER TRACK	004	TRAIN NO., TRACK NO., POSITION 1ST. CONTAINER, POSITION LAST CONTAINER
PLACE EMPTY FLAT CARS IN TRACK	005	TRAIN NO., TRACK NO., POSITION 1ST. CONTAINER, POSITION LAST CONTAINER
REMOVE EMPTY FLAT CARS FROM TRACK	006	TRAIN NO., TRACK NO., POSITION 1ST CONTAINER, POSITION LAST CONTAINER
OUTBOUND BLOCK CUT OFF	010	TRAIN NO., TRACK NO.

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Description of Event Records

MACHINE EVENTS

EVENT DESCRIPTION	NUMBER	PARAMETERS
MACHINE STARTS SHIFT	200	MACHINE NAME, TYPE, NUMBER, XPOSIT, YPOSIT
ENDS SHIFT	201	" " " " "
MACHINE STARTS BREAK	210	MACH. NAME, TYPE, NUMBER, XPOSIT, YPOSIT
ENDS BREAK	211	" " " " "
MACHINE LOADS CONTAINER ON FLATCAR	220	MACH. NAME, TYPE, NO., DURATION, TRAIN,
MACHINE SPOTS CONT. BESIDE TRACK	221	TRACK NO., POSITION, LOAD, ORIG., LENGTH " " " "
MACH. UNLOADS CONT. FROM FLATCAR	225	MACH. NAME, TYPE, NUMBER, DURATION, TRAIN,
MACH. PICKS UP SPOTTED CONTAINER	226	TRACK NO., POSITION, LOAD, ORIG. LENGTH " " " "
MACHINE PLACES CONT. IN STORAGE	230	MACH. NAME, TYPE, NUMBER, DURATION, STORAGE NO.,
MACHINE PLACES CONT. IN STORAGE (OVERFLOW)	231	ROW, COL., LEVEL, LENGTH " " " "
MACH. PICKS UP CONT. IN STORAGE	235	MACH. NAME, TYPE, NUMBER, DURATION, STORAGE NO.
REMOVES CONT. FROM STOR. (OVERFLOW)	236	ROW, COL., LEVEL, LENGTH " " " "
MACHINE PLACES CONT. ON TRUCK	240	MACH. NAME, TYPE, NUMBER, DURATION, LOAD,
MACHINE PICKS UP CONT. ON TRUCK	241	ORIGIN, LENGTH, INDEX FOR LOCATION OF LOADER, CONTAINER NUMBER. " " " "

Description of Event Records

MACHINE EVENTS

EVENT DESCRIPTION	NUMBER	PARAMETERS
MACHINE TRAVELS WITH CONTAINER	250 LOADER	MACH. NAME, TYPE, NUMBER, DURATION, START OBJ., END OBJ., LOAD, ORIGIN, LENGTH, SPOT.
	250 CRANE	MACH. NAME, TYPE, NUMBER, DURATION, OBJECT NO., SPOT.
MACHINE TRAVELS WITHOUT CONTAINER	251 LOADER	MACH. NAME, TYPE, NUMBER, DURATION, START OBJ. NO., END OBJ. NO., SPOT.
	251 CRANE	MACH. NAME, TYPE, NUMBER, DURATION, OBJECT NO., SPOT.

Description of Event Records

MISCELLANEOUS EVENTS

EVENT DESCRIPTION	NUMBER	PARAMETERS
TRUCK MOVES WITH CONTAINER	300	TRUCK NAME, TYPE, NUMBER, DURATION, START OBJ., END OBJ., LOAD, ORIGIN, LENGTH, CONTAINER NUMBER.
TRUCK MOVES WITHOUT CONTAINER	301	TRUCK NAME, TYPE, NUMBER, DURATION, START OBJ., END OBJ.
GATE QUEUE	320	NO. CONTAINERS WAITING TO ENTER' NO. CONTAINERS WAITING TO EXIT.